IN TWO SECTIONS

SECTION ONE 1936

THE AMERICAN WELDING SOCIETY JOURNAL

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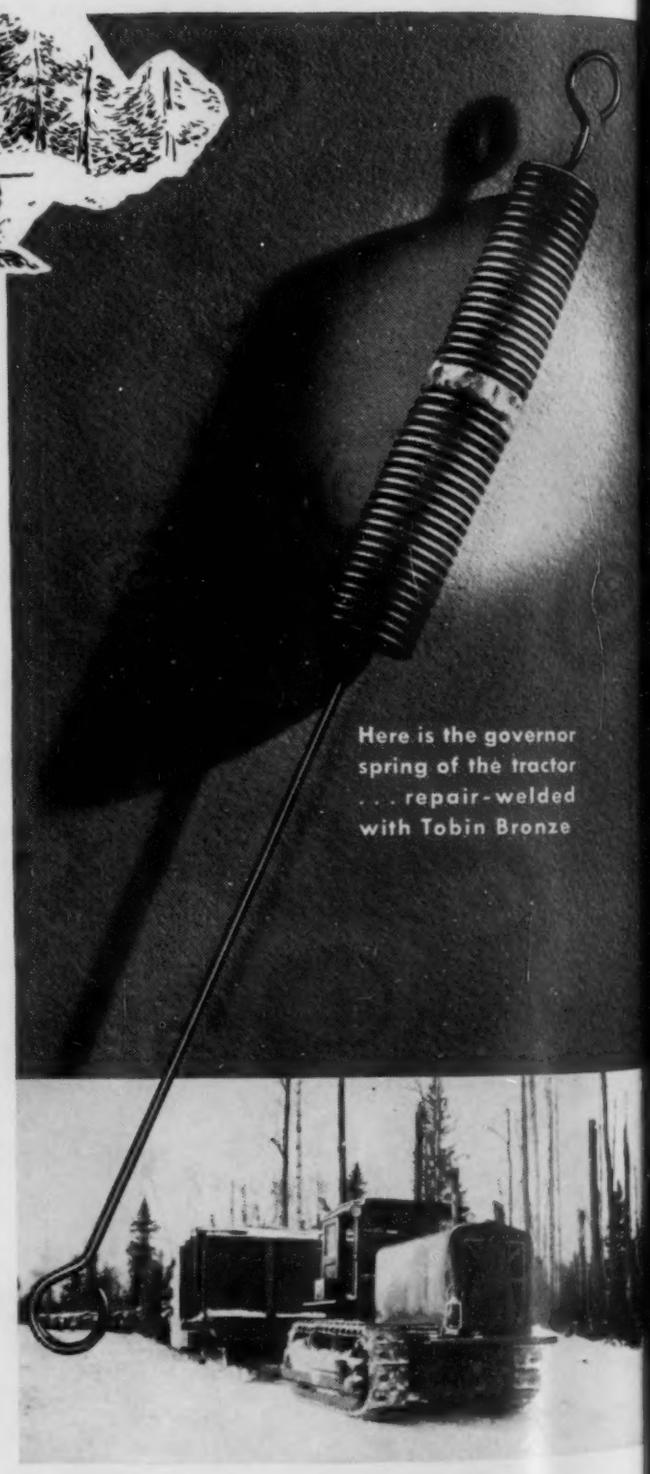
Tobin Bronze to the Rescue

AT 42° BELOW ZERO



Here is the governor spring of the tractor . . . repair-welded with Tobin Bronze

Anaconda Welding Rod used to repair stalled tractor . . . and tie-up of large logging operation was prevented

Many times Tobin Bronze has been called upon for unusual and difficult repair jobs when disabled machinery threatened to lose money for owners. But never did it prove its value more thoroughly than in Manitoba last winter when the thermometer stood at 42° below zero.

One night in January, the 75-horsepower Diesel tractor used by the Pas Lumber Company on a log haul stopped suddenly, with its big "train" of spruce logs only half-way to its destination.

Because of the intense cold, fires were started under and around the tractor . . . the usual practice with a stalled machine in the North. Examination showed that the governor spring had broken. The tractor was helpless . . . and the nearest point where a new spring could be obtained was *over five hundred miles* away.

A search for a spring which might be substituted proved useless. Welding was the only way out. And then . . . Tobin Bronze came to the rescue.

A metal thimble was used inside the spring to keep the parts in line while they were being joined by a collar of Tobin Bronze. The part was then replaced and the tractor continued to work splendidly until a new spring was obtained, two weeks later.

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THE AMERICAN WELDING SOCIETY JOURNAL

WM. SPRARAGEN, Editor | VOL. 15 | NO. 12

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Contents

Technical Papers, Items and Reports

	Page
Gas Tight Welded 58,000 kva. Hydrogen Cooled Turbo-generator Frame (Courtesy Westinghouse Elec. & Mfg. Company)	Front Cover
Thermit Welding, by *J. H. Deppeler*	2
Discussion of paper by W. L. Warner, on "Arc Welding of Structural Alloy Steels," by *F. T. Llewellyn*	8
Welded Patrol Boats, by *Edgar Schellenbach*	8
Technique for Resistance Welding Ferrous and Non-Ferrous Sheet Metals, by *E. I. Larsen*	9
Sensitivity to Welding Cracks	16
Question and Answer Column	17
Report on Some Impact Tests of Fillet Welds, by *Wendell F. Hess*	18
Discussion of Paper by Dr. Jacobus on "Recent Practice in Fusion Welded Boiler Drums"	19
Discussion of Article by Messrs. Rooke, Saacke and Kugler on "Multi-Layer Oxyactylene Pipe Welding," by *G. W. Plinke* and *A. S. Douglass*	21
Some Pictures of Welding Applications: New High-Pressure Locomotive Boiler Is First of Its Type, by *A. F. Davis*	24
Welded Smoke Stacks, by *George McNutt*	24
Welding Repairs Damaged Barges, by *R. W. Orth*	25
Current Welding Literature	25

Society and Related Activities

New Appointments	27
Inspection Trip at Cleveland	27
Arc Welding Standards	27
Protective Glasses	27
Bound Volume Journal	27
A Message from Our President	27
Obituary—Frank P. McKibben	28
Welding Handbook	28
Section Activities	30

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Thermit Welding*

By J. H. DEPPELER†

ONE of the first questions that generally arises in any discussion of Thermit welding is how a cast steel, such as that produced by the Thermit reaction, can compare in strength with forged steel, and will not the strength of the welded part be simply that of the cast steel in the weld rather than that of the original forging. In order to understand fully why Thermit steel has all the physical properties of forged steel, and why test pieces just as often fail completely outside the welded area as they do in the weld or in the metal adjacent to the weld, it is necessary to know something of the nature of the Thermit reaction.

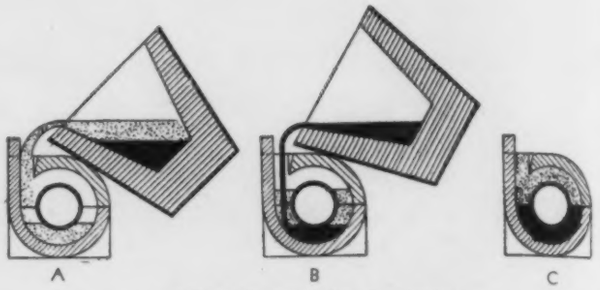
The Thermit welding process depends principally on the alumino-thermic reduction of iron oxide, by which molten iron is produced, in somewhat the same manner as when carbon is employed as a reducing agent in producing iron from iron ore. Carbon, however, requires the application of considerable external heat to cause it to react with the oxides, while aluminum, because of its greater affinity for oxygen, reacts much more actively and requires little or no external heat. The basic Thermit mixture, consisting of iron oxide and pure aluminum, needs only to be ignited in order to react rapidly, according to the chemical formula $3\ Fe_3O_4 + 8\ Al = 4\ Al_2O_3 + 9\ Fe$. The reaction generates a terrific heat and the temperature of the resulting iron is approximately double the temperature of ordinary molten steel. Of course, in order to provide steel rather than pure iron, additions are made to the basic Thermit mixture, and even the physical properties of Thermit steel are readily controlled in this manner. For example, by introducing various metallic elements into the weld metal, either by means of metallic pieces, which are melted in the reaction, or, in the form of Thermits or combinations of oxides of the elements with aluminum, tensile strengths ranging from 50,000 lb. to 110,000 lb. per square inch with corresponding ductilities may be produced. The efficiencies of a number of metallic oxides in the reaction are also known and the accompanying table (Fig. 1) shows the aluminum reduction of these oxides and the chemical analyses of the resultant slags and metals.

It is, however, the fact that Thermit steels are produced through the reaction of a very pure iron oxide by an almost perfectly pure aluminum that largely accounts for these steels having physical properties similar to forged steels without the necessity of refinement by working. Ordinary cast steels are refined from pig iron and other impure materials. On solidifying, these impurities tend to gather at grain boundaries and cast steel fractures are usually along grain boundaries, in this area of impurities. The purity of the thermit ingredients eliminates most of this grain boundary impurity and the fractures are forced to go through the grains. The physical properties are, therefore, comparable to those of forged and worked steel.

Formulae Showing the Aluminum Reduction of Various Oxides

Metallic Oxides		Aluminum		Resultant Slag		Resultant Metal
$3Fe_3O_4$	+	8Al	=	$4Al_2O_3$	+	9Fe
Fe_2O_3	+	2Al	=	Al_2O_3	+	2Fe
$3Mn_3O_4$	+	8Al	=	$4Al_2O_3$	+	9Mn
Cr_2O_3	+	2Al	=	Al_2O_3	+	2Cr
WO_3	+	2Al	=	Al_2O_3	+	W
$3V_2O_5$	+	10Al	=	$5Al_2O_3$	+	6V
$3TiO_2$	+	4Al	=	$2Al_2O_3$	+	3Ti
3NiO	+	2Al	=	Al_2O_3	+	3Ni
MoO_3	+	2Al	=	Al_2O_3	+	Mo
$3SiO_2$	+	4Al	=	$2Al_2O_3$	+	3Si
B_2O_3	+	2Al	=	Al_2O_3	+	2B
$3Co_3O_4$	+	8Al	=	$4Al_2O_3$	+	9Co

Fig. 1



THERMIT PIPE WELDING OPERATION

A—Slag flowing into mold and coating outside of pipe and inside of mold
B—Slag in mold and steel following, displacing slag in bottom part
C—Both slag and steel in mold but steel separated from pipe and mold by film of slag

Fig. 2

The Thermit process of welding includes two distinct methods or classifications. In the first, only the heat of the slag and the heat of the metal resulting from the reaction is utilized. In the second, the Thermit steel is deposited as weld metal.

Among the applications of the first of these methods is that of pipe welding. The accompanying diagram (Fig. 2) shows the way in which the slag and the superheated Thermit steel are used to bring the pipe to welding temperature. Following this operation, special clamps, which are attached to the pipes with the mold, are drawn up to force the ends of the pipes together and provide a pressure butt weld. While this method of welding pipe has a number of advantages, including great strength, with little, if any, alteration of the inside diameter of the pipe, it is somewhat more costly than electric or acetylene welding and its use consequently has been limited. Of late, however, manufacturers of superheaters and similar equipment are beginning to employ Thermit pipe welding in the assembly of large units, which are built in sections in their own plants and then put together in the field.

One of the principal uses for the method in which the Thermit steel is employed as weld metal has been the welding of street railway rails. In fact, the elimination of rail joints and the joining of rails in the long continuous stretches by Thermit welding has been standard in the street railway industry for more than twenty years. At present about 85 per cent of all rail welding done by the street railways is Thermit welding. Quite naturally, the development and improvement of both equipment and procedure in this field have been extensive and today the process is advanced to the point where street railways are welding rails under traffic, that is, with cars operating over the rails while the work is going on.

* Paper presented at the Annual Convention of AMERICAN WELDING SOCIETY, October 21, 1936, Cleveland.

† Chief Engineer, Metal & Thermit Corporation.

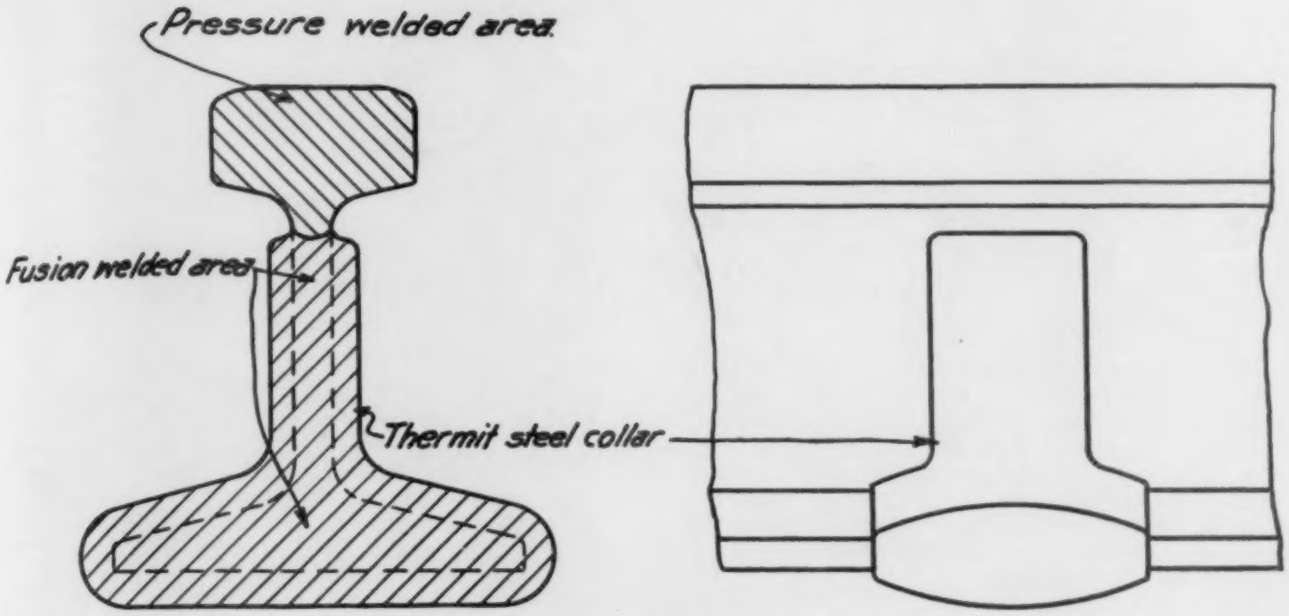


Fig. 3—Pressure-Butt Thermit Weld

A still more recent development, however, is in the railroad field, where the tendency is toward increasingly high operating speeds and the rail joint problem has become an acute one, both from the standpoint of safe operation and from that of maintenance expense. The American Railway Engineering Association estimates, for example, that with standard track construction some 45% of total track maintenance is due at the present time to rail joints. Naturally, higher operating speeds will tend to make the condition worse rather than better, and for a number of years the solution to this problem has been uppermost in the minds of many track engineers. The use of longer and longer rails, an increase in standard rail lengths from 30 to 33, and, finally, to 39 feet in the United States, to 60 feet in England, and to 90 to 100 feet in Germany, has been simply an effort to reduce the number of rail joints in a given length of track. The next logical step, however, was to find some means of eliminating rail joints entirely and three years ago the first installation, involving considerable lengths of continuous rails, that is, rails Thermit welded together into long stretches without joints of any kind, was made on main-line track in this country. Up to that time, such a thing had largely been considered impossible because every one knew that contraction and expansion in rails of any considerable length would be practically impossible to cope with.

The street railway industry had, of course, solved the problem long since but most of the street railway installations were in paved streets where the bugaboo of expansion was not an important factor. There were, however, certain long stretches of welded rails on so-called open track in street railways and a study of these stretches indicated that expansion difficulties were far less important than had been thought. In addition, it had been the practice of six or seven years to weld rails in some of the countries abroad and the German State Railroads had experimented from 1928 to 1932 with express track, in which standard 30-meter rails were welded together to form 60, 120 to 300-meter lengths, and in 1932 they determined that where two continuous rails 120 meters long were placed in track and alongside of the right-of-way similar lengths of continuous rails were placed on rollers where they could expand and contract freely, the maximum gap between the rails in the track during the course of a year was 12 mm., while in the case of the long rails on rollers the maximum gap mounted to 65 mm. during the same period of time. In addition, the German roads made a number of installations of long welded rails on bridges and in tunnels, and in England considerable welding of rails into 225-foot stretches was done, while in France the welding of rails into 100-meter lengths had become standard practice, and experiments with even greater lengths had proved successful. In Australia welded rails of 225 feet had also become standard.

All of the welded track in Europe, however, involved only light wheel loads and relatively small soft rail, that in Germany, for example, being approximately 0.40 carbon and weighing only 97 lb. per yard, and none of the railroads in this country believed that the heavier higher carbon rails in general use here could be welded successfully until the Delaware & Hudson road pioneered with several experimental installations, using a new type of Thermit weld which combined a pressure butt weld of the rail heads with a fusion weld of the webs and bases (Fig. 3).

In connection with these early installations on the Delaware & Hudson, it was estimated that a standard 39-foot rail prevented from expanding or contracting would develop a stress of 19,000 lb. per square inch with each 100° F. change in temperature. For the entire thirteen square inch cross section of a rail this would amount to 247,000 lb. which seemed an almost impossible force to hold but was well within the elastic limit of the steel so that the rail in any event would return to its original length when the initial temperature again prevailed.

Now with the M. & L. construction employed on the Delaware & Hudson, it was figured that the spring pressure resistance to end movement and the frictional resistance between tie plate and rail provided by the spring clips, combined with the gagging action of the double shoulder tie plates and the weight of the rail itself, should be ample to prevent end movement of the long rails. In the first installation of Albany, however, comprising 2700-foot rail lengths, some safety measure seemed desirable and based on a theoretical expansion of 2 feet 8 inches over a temperature change of 150° F., and figuring on only partial restraint from the

track fastenings, an experimental expansion joint, allowing 1 foot 10 inches of movement, was installed 180 feet from the end of one of the long welded rails. As it turned out, this joint showed no appreciable movement from winter to summer and has since been removed.

Altogether there have been four installations on the Delaware & Hudson. The first of these at Albany in the summer of 1933 involved 318 welds and consisted of curved double track 2700 feet long. The rail here is 130-lb. medium-manganese, while annual traffic over this stretch consists of 12,000,000 tons northbound and 4,285,000 tons southbound at a maximum speed of twenty miles per hour. The average wheel loads are 26,800 pounds.

The second installation on the Delaware & Hudson was the following year when 254 welds were made, forming 131-lb. rails into 2000-foot continuous lengths in tangent double track at Mechanicsville, N. Y. Annual tonnage over this stretch is 3,000,000 tons in each direction, while the average wheel load is 40,000 pounds.

In the same year, 1934, another stretch, consisting of mile long continuous welded rails in double track, was installed at Windsor, N. Y.

The following summer, perhaps the most interesting of all the installations on this road was put in at Schenectady, N. Y. (Fig. 4). Here lack of room prevented welding "on location" and the plan was evolved of welding the rails together on top of long strings of flat cars in the Mohawk Yards more than three miles away. With the rails welded into 720- and 1480-foot lengths, a locomotive and derrick were coupled on the train was hauled to the cite of installation (Fig. 5). Here the derrick hooked on to the ends of the rails lifting them off the cars and on to the roadbed and the remainder of the long rails was barred off the train by workmen. Although not secured to the cars in any way, the long rails bent easily to conform to the curvature of the track during transportation, even when rounding a 10° curve. The unloading of the 1480-foot rail in this manner took only about 15 minutes. Each of these long lengths was cut into the track as soon as unloaded and later all were joined together by closure welds to form rails 11,787 feet long continuously welded, except for a pair of insulated joints installed for signal circuit purposes approximately 7000 feet from one end of the stretch. The work involved 551 Thermit welds and 70 electric flash welds. The rail was 131-lb. rail, some plain carbon steel, some medium-manganese, some carbon-molybdenum and some manganese-molybdenum. Annual traffic over this track is around 9,000,000 tons, freight only, and wheel loads average 40,000 pounds.

All of the welded track on the Delaware & Hudson has been put in with M. & L. construction and the road does not feel particularly concerned about safety in the event of a fractured weld. The double shoulder tie plate and the spring rail clip are relied on to prevent the rail from getting out of alignment. If breaks should occur at joints or elsewhere throughout the rails because of defects, it is expected that joint bars will have to be applied temporarily and the break welded later, adding a short length of rail in some cases to assure a sound rail structure.

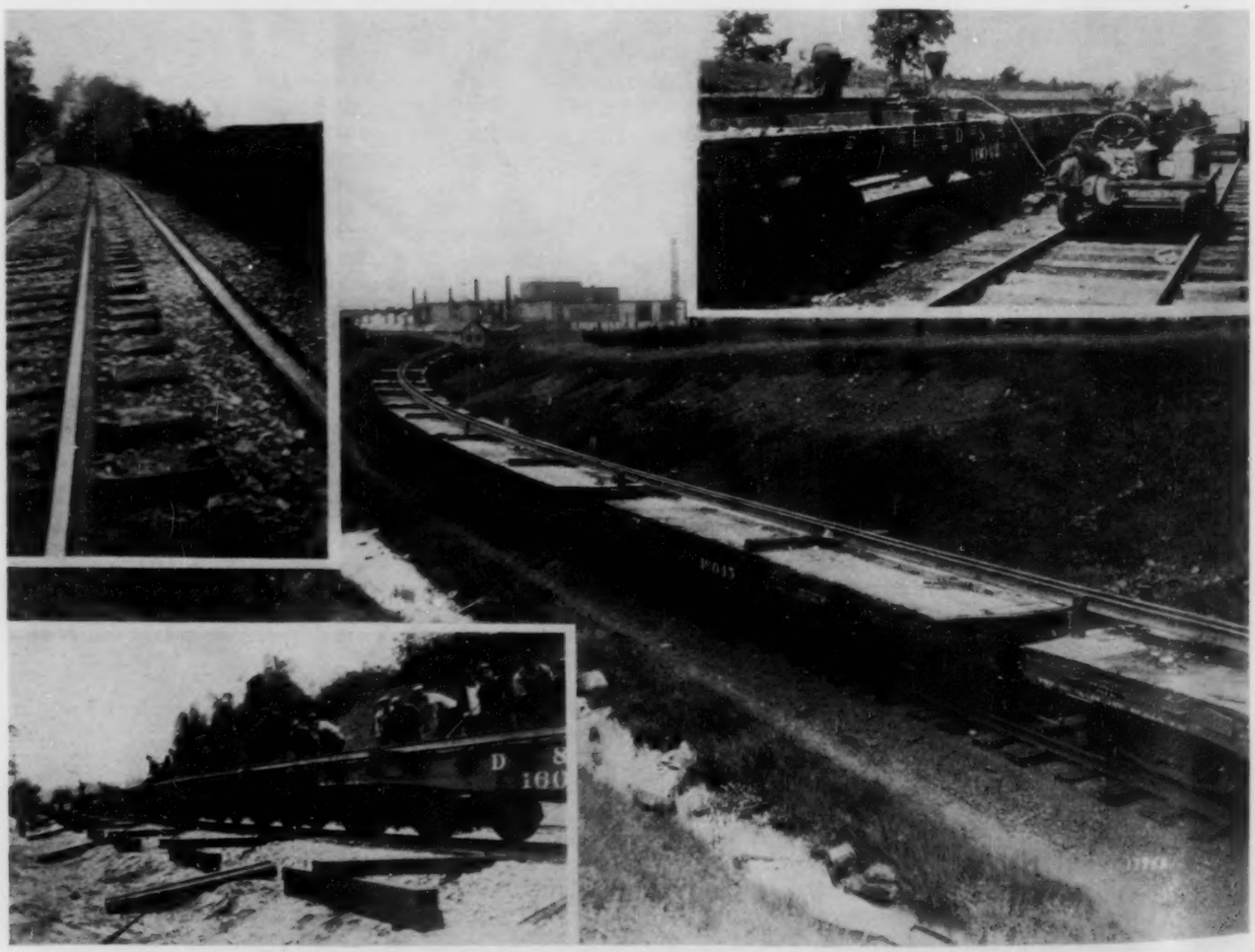


Fig. 4—The Long Rails at Schenectady, on the Delaware & Hudson Were Welded into 700 ft. and 1400 ft. Lengths on Top of Flat Cars in a Yard Three Miles Away, Then Hauled to the Site of Installation, Barred Off the Cars, and Placed in the Track

Fig. 5—The Rails in the Track at the Right Are Welded into Twelve Thousand Foot Lengths, Continuous Except for a Pair of Insulated Joints, Installed for Signal Circuit Purposes, Seven Thousand Feet from One End of the Stretch

On the Bessemer & Lake Erie Railroad in 1935 a mile of single track with 269 welds was installed at River Valley, Pa., using GEO construction (Fig. 6). Eighteen hundred feet of this track is tangent track, 2000 feet is on a 1° 30 minute curve, and 1500 is on a 5° curve, approximately half is level and the other half on a 0.65 grade. Annual traffic consists of 9,000,000 tons with wheel loads of 37,900 pounds. Traffic is both passenger and freight with trains operating at maximum speeds of 55 and 35 miles per hour, respectively. The rail was laid with the atmospheric temperature at approximately 65° F. and has since been through weather extremes ranging from 100° F. to minus 20° F.

Other and more recent installations have been welded rails a half mile long in a tunnel on the Erie Railroad at Otisville, N. Y., two continuous stretches of single track, each 4000 feet long, in tunnels on the Northern Pacific Railway in Montana, and twenty-two lengths of long rail in double track in an open cut on the Brooklyn & Queens Transit Corporation, part of New York City's subway system, in Brooklyn, (Fig. 7). The Northern Pacific Railway installations are of particular note in that the work was done under circumstances similar to those at Schenectady, N. Y., except that the rails were welded into 4000-foot lengths on top of the cars, which were equipped with rollers for the rails to rest on. The trains were then pulled into the tunnels and broken at the center so that when locomotives were hitched to each end the cars were simply pulled out from under the rails and they settled to the roadbed.

The behavior of all these long welded rails in service is a particularly interesting subject. The experience of the Delaware & Hudson with its early installations indicated that at the ends long rails have little more if any expansion or contraction than would be expected with 39-foot rails in ordinary track construction. This served to bear out the conclusions reached by the German engineers several years previously that the amount of movement at the ends, where the rails were

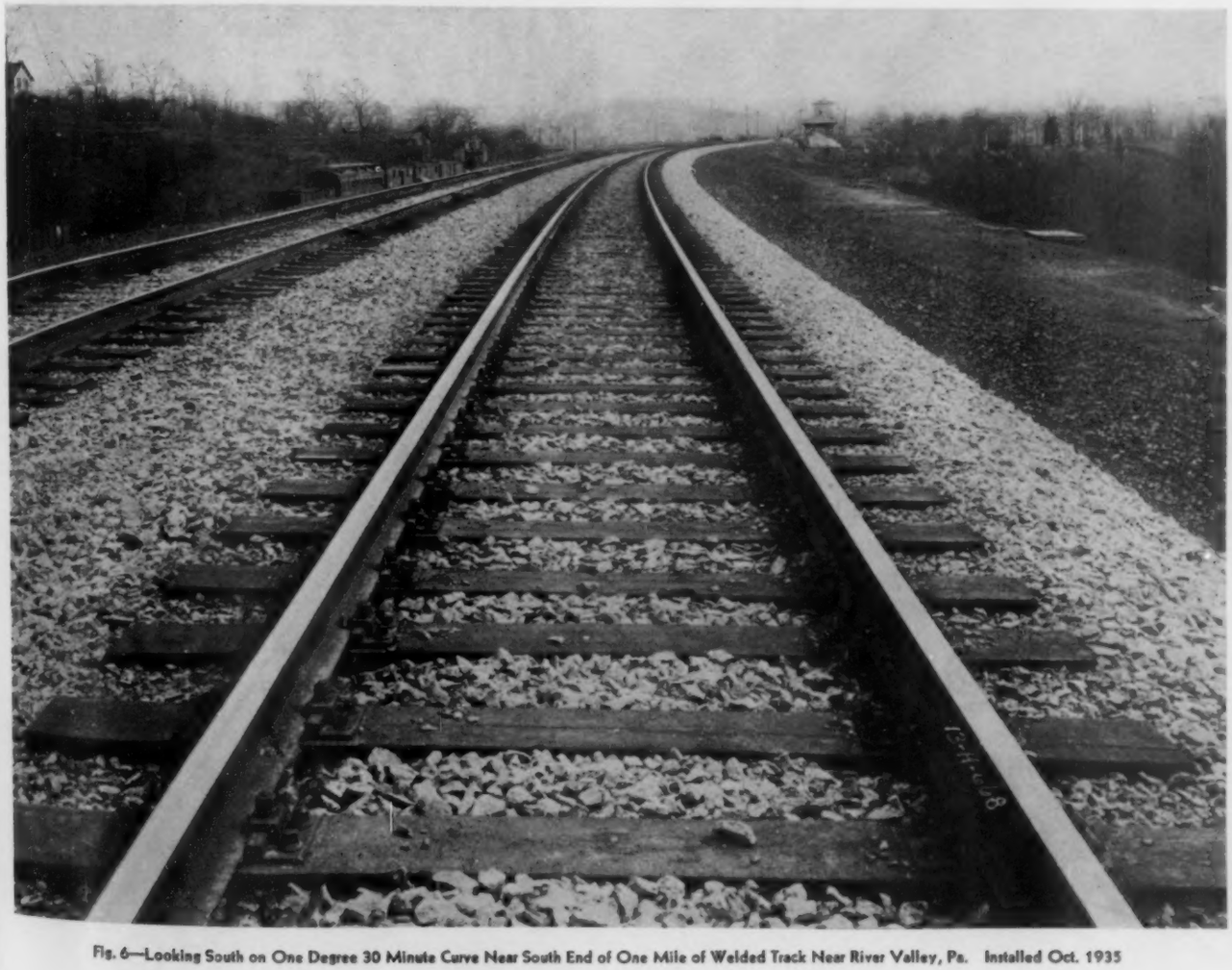


Fig. 6—Looking South on One Degree 30 Minute Curve Near South End of One Mile of Welded Track Near River Valley, Pa. Installed Oct. 1935

Fig. 7—Long Welded Rails Ready for Installation in an Open Cut on the N.Y. & Q. R.T. Co. Subway in Brooklyn, N. Y.

100, 200 or 400 feet long, was apparently only the normal movement for 40-foot rails. At Albany, where the rails averaged about 125° F. in temperature during welding and the final closures in the tracks were made during even warmer weather with the rails at a temperature above 130° F., they have been through some of the coldest winters ever experienced in that section, yet up to the present time have shown practically no movement whatever. For example, on December 29, 1933, when the temperature of the east rail was at 5°, the joint at the north end was $^{5}/_{16}$ inch and at the south end was $^{3}/_{8}$ inch, whereas on June 11, 1934, when the same rail had a temperature of 95°, the openings at the same joints were zero and $^{3}/_{16}$ inch, respectively. Similarly considering, the west rail in north and south end joint openings on December 28, 1933, were $^{5}/_{16}$ inch and $^{1}/_{2}$ inch, respectively, while the openings at the same joints on June 11, 1934, were zero and $^{1}/_{4}$ inch. Between the extremes of temperature recorded, the maximum change in size of any of the joint openings was $^{5}/_{16}$ inch and that occurred at two joints which had a maximum opening of this amount when the rail registered 5° above zero. Frequent measurements made on other long rails on the Delaware & Hudson have revealed almost identical behavior under wide variations in temperature.

On the Bessemer & Lake Erie Railroad the mile long rails at River Valley have been under careful and constant observation and the results shown in the accompanying table (Fig. 8) indicate the selfsame type of behavior.

On the Delaware & Hudson it has also been found that all the welded stretches have kept their alignment well, even on curves including the 7° 30 minute curve at Albany. No noticeable movement of the ties in a direction longitudinal of the track has been found.

As to the cost of these Thermit welds, which up to the present time has seemed somewhat high, there is no question but that as further work is carried on and track forces familiarized with the procedure, the price can be cut down considerably. At any rate, the amount of saving which can be made in maintenance, while still somewhat problematical, seems to be many times more than enough to offset the increased cost of the weld over the joint, as well as both the possible increased cost of laying rail originally and the increased cost of changing each rail in case of a break, including the extra cost of the two welds required. These savings may be outlined as follows:

(1) Elimination of rail joints.

(2) Increased life of rails through elimination of rail batter.

(3) Saving in labor required in relaying rail through increased life of rail.

(4) Reduced mechanical wear of joint ties with resultant increased life of ties.

(5) The substitution of a standard intermediate tie

plate for the larger and more expensive plates used on the joints on some roads.

(6) More efficient track signal circuits, saving the cost of installing and maintaining bonds.

(7) Reduced maintenance of rolling stock and motive power.

In connection with the first of the above items, in various studies which the Committee on Economics of Railway Labor of the American Railway Engineering Association has made, it is figured that approximately 65% of the track labor is chargeable to track laying and surfacing and that very nearly 75% of this charge covers the labor used in tamping at or near the joint. Thus, over 45% of track labor is now required to keep the rail joint itself in proper line and surface and it goes without saying that if this amount of labor should prove to be saved by welding rails into long lengths, the welds could cost many times the present figure and still be economical to install.

Still another field in which Thermit welding, because of its inherent advantages as an emergency repair method, particularly where very heavy sections of ferrous metals are involved, has been put to extensive use, is the iron and steel industry. An interesting sidelight illustrating the extent to which the process is here being employed is a questionnaire sent to every important steel mill in the country by an engineering association within the industry. Almost 80% of the mills that replied to this questionnaire said they used Thermit for heavy repairs, and without exception reported 100% excellent results

The widespread acceptance of Thermit welding in this field is primarily due to three factors:

1. The low cost of Thermit repairs in contrast to the cost of new parts for replacement, as in the case of the broken bending roll 3 feet in diameter and 42 feet long, which cost $8000 less to repair permanently with Thermit than to replace.

2. The speed with which these repairs can be made compared with the length of time required to obtain and install new parts, such as the huge 82-ton plate mill housing 22 feet high and 10 feet wide, which was repaired in two places in one week's time with Thermit.

3. The dependability of the welds made and the fact that repairs are permanent repairs which frequently result in parts being made stronger than when new. Many heavy parts, which have failed after brief service, have, for example, been reclaimed by Thermit to give years of satisfactory service.

These factors combine to make Thermit welding of genuine economic importance in steel mill operation. They provide the superintendent and the master mechanic with a low cost method of meeting emergencies; they prevent long and costly shutdowns of whole departments which reduce production of entire mills due to breakdown of essential equipment.

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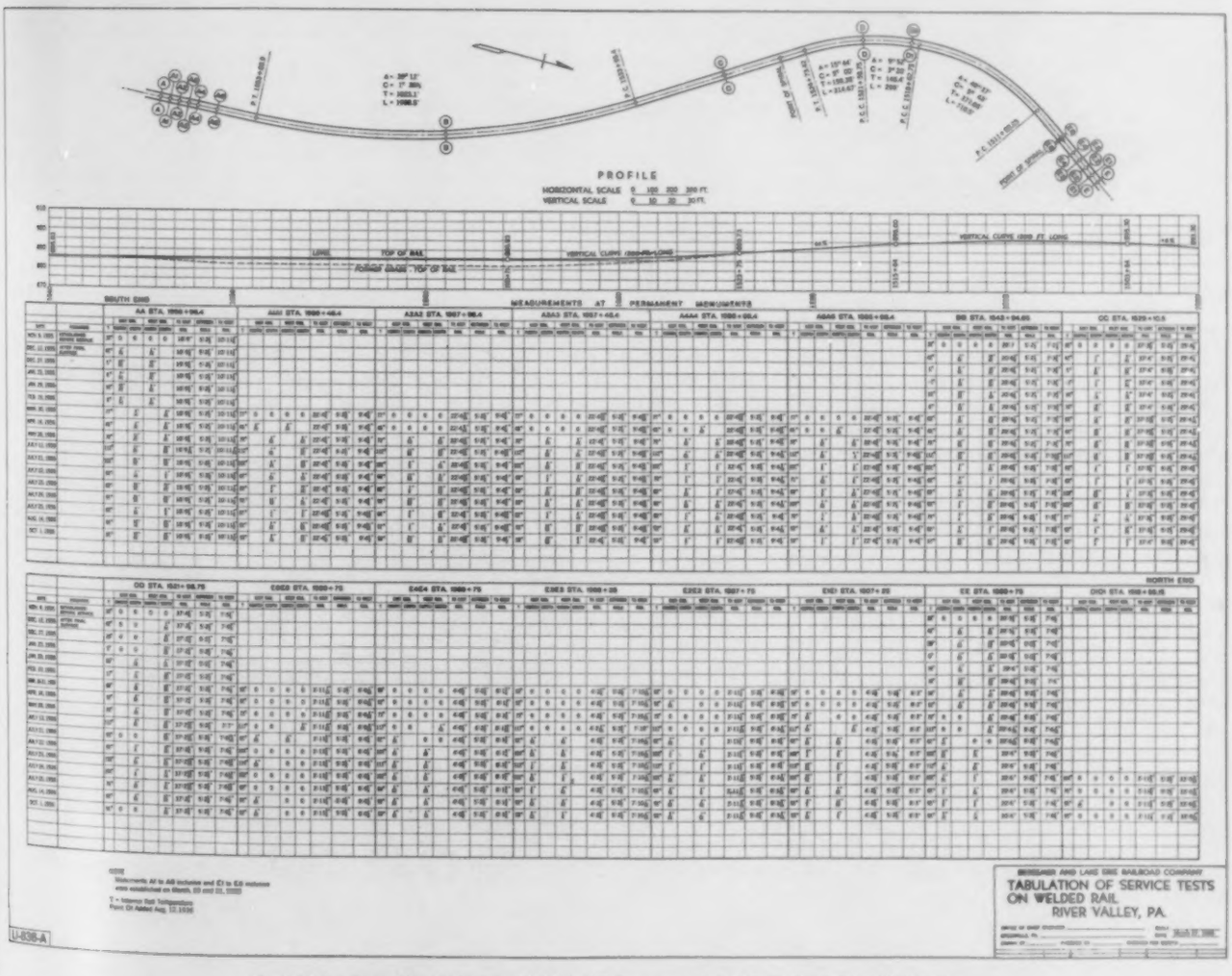

Fig. 8—Tabulation of Service Tests on Welded Rail, Bessemer & Lake Erie Railroad, River Valley, Pa.

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Discussion of paper by W. L. Warner, on "Arc Welding of Structural Alloy Steels"*

By F. T. LLEWELLYN**

ALTHOUGH this paper is admittedly only a progress report, it presents valuable information relative to a large and meritorious program of investigation that is being carried out by Mr. Warner at the Watertown Arsenal. While many of the results will have wide application, the present discussor believes that the title of the paper should be qualified by some such phrase as, "especially as applied to the construction of ordnance." Otherwise there is the danger of assuming that the conclusions are directly applicable in all fields of use.

Mr. Warner recommends that a maximum limit of 0.25 per cent be set on the carbon content of weldable alloy steels. A suspicion arises that he rather expects steelmakers to take issue on this point. The present discussor sees no reason to do so. Indeed, it is his reaction that, in some cases, Mr. Warner's proposed limit may be too liberal.

The report lists thirteen different grades of low-alloy high-tensile steel. Apparently the only properties on which tests have so far been completed are ultimate and yield point values. Based on these properties alone, Mr. Warner presents a comparison by the aid of which he suggests that designers may select the grade which should most satisfactorily meet their strength requirements. Mr. Warner quite properly points out, however, that other factors may change the desirability of any of these steels for a given welded structure.

It is assumed that the final report will present a more comprehensive classification that takes impact resistance into consideration. The behavior of a few of the grades under tension impact is shown in the charts and doubtless, when all the tests have been completed, Mr. Warner will present another classification in which all the results are included. Meanwhile, designers should recognize that the comparison is not yet complete.

In addition to the properties included in the Watertown investigation, there are frequently cases where resistance to fatigue and to corrosion become critical. These properties also should be considered in any attempt at a general ranking. In industrial applications the comparative cost per pound of the respective steels is another feature which will sometimes determine their optimum suitability in a design.

Mr. Warner is to be congratulated on this progress report. His final report will be awaited with interest.

* Presented at Joint Session AMERICAN WELDING SOCIETY and American Society of Mechanical Engineers, Cleveland, Oct. 22nd.
** Research Engineer, United States Steel Corporation.

Welded Patrol Boats

By EDGAR SCHELLENBACH†

PICTURED with Cincinnati's skyline in the background is one of a group of speedy patrol boats that will soon become a part of the revenue service of Colombia, South America.

The boats, built by the Modern Engineering Company, of Covington, Ky., were ordered by the coast guard patrols of the South American Republic, where they will be used to combat smuggling and banditry.

Especially noteworthy are many unusual features in construction. Although it is 30 feet long, has a 10 foot beam and weighs 10,000 pounds, it will draw only 11 inches with an average load.

The speedy crafts are made of $^3/_{16}$ inch Armco hot rolled steel plates. All seams are sealed by an automatic electric arc welding process. The motive power is supplied by a Ford V-8 marine adapted engine installed in the hull. At "full speed" the boats will attain 15 miles an hour.

Boat Constructed of Armco Hot-Rolled Steel Plates for Use in Revenue Service in Colombia, South America

† Armco Publicity Department.

Technique for Resistance Welding Ferrous and Non-Ferrous Sheet Metals*

By E. I. LARSEN†

Introduction

A GREAT many papers have dealt with various phases of resistance welding. Most of these papers, however, have been of a general nature or have dealt with one or two specific problems relating to resistance welding or the welding of some particular alloy or metal. The present paper is more or less in the nature of a correlated abstract covering the more important aspects of resistance welding of all of the important ferrous and non-ferrous alloys now being welded.

In the preparation of this paper the author has taken a great deal of published data from various sources.[1]

As is well known by those connected with the use of resistance welding to fabricate sheet metals there are a great many variables. Some of these variables can be changed over wide ranges without affecting to any great extent the quality of the resulting weld. The data, therefore, presented in this paper are not guaranteed to be those which will produce the most satisfactory results on any or all welding operations. It is thought they are more or less average and will give the reader an idea as to the correct ranges in which to work.

General

Welding is a combination of heat supplied by electric current (Joule heat) and pressure used for joining together two or more pieces of metal. The welding process itself has its basis in the recrystallization of the metal. The pressure required in the process serves several purposes:

1. It presses the surface of the metals close together.
2. It breaks through the films of oxides, nitrides and adsorbed gases that are found on the surface.
3. It provides a small deformation in the crystals of the original metal that will permit them to recrystallize during the welding operation. During this process of recrystallization the grains may grow across the interfaces that separated the two pieces. As this grain growth occurs, the two pieces are welded together.

In the welding of certain non-ferrous metals it is necessary to actually melt the metal in the interfaces in order to produce the recrystallization which causes the two pieces to be welded.

Welding Heat

(*a*) *Electrical Conditions.*—The amount of heat generated depends upon the current flowing through the pieces to be welded and the resistance of the surface contact areas. This can usually be explained as follows:

$$\text{Heat in Kilo-Calories} = 0.238 \times R \times I^2 \times T \times 10^{-3}$$

R = resistance
I = current
T = time
0.238 = conversion factor (1 Joule = 0.238×10^{-3} Kilo-Calories)

The resistance consists of the following three parts: (1) Resistance between electrode and work. (2) Resistance between the two sheets to be welded. (3) Specific resistance of the sheets.

The resistance of items one and two depends upon the pressure used. The following other factors enter into the resistance: (1) Surface condition of the material (rough, smooth, scaly, etc.). (2) Shape and size of the electrode. (3) Electrode material. (4) Surface condition of the electrodes.

From the above it is evident that the shape, size, surface condition and chemical composition of the electrodes and the pressure on the electrodes must be adjusted to suit certain types of metal and certain surface conditions of the material to be welded. If the material to be welded has an electrical conductivity much lower than that of the electrodes most of the heat will be generated between the pieces to be welded. If, however, the material to be welded has a higher electrical conductivity than the electrode material then heating will occur also at the point where the electrode is in contact with the work and the welding face of the electrode may stick to the sheet.

In order to retain the highest possible electrical conductivity in the electrode material it is necessary that efficient water cooling be used, otherwise the electrical conductivity will decrease due to increased temperature. This is true for copper and copper base alloys and as an example the values for pure copper are given below:

Table 1

Temperature		Per Cent
Centigrade	Fahrenheit	Electrical Conductivity
20	68	100
100	212	75
200	392	58
300	572	50
400	752	43
500	932	35

The thermal conductivity of copper decreases less rapidly as is evident from the following table:

The thermal conductivity shown in Table 2 applies, however, only to pure copper as in most of the copper base alloys now used for resistance welding electrodes the thermal conductivity increases slightly with the temperature rise obtained during most resistance welding opera-

* Paper presented before AMERICAN WELDING SOCIETY in Cleveland, Ohio, October 21, 1936.
† P. R. Mallory & Company, Inc.
[1] See bibliography at end of paper.

tions. As an example, the thermal conductivities of some commercial alloys are listed in Table 3.

Table 2

Temperature Centigrade	Temperature Fahrenheit	Thermal Conductivity Cal./cm.²/cm./sec./deg. C.
20	68	0.912
100	212	0.901
200	392	0.890
300	572	0.879
400	752	0.867
500	932	0.856

Table 3

Material	Thermal Conductivity Cal./cm.²/cm./sec./deg. C. 20° C. (68° F.)	200° C. (392° F.)
Elkaloy	0.824	0.841
Mallory 3	0.820	0.827
Mallory 53	0.403	0.487
Mallory 73	0.245	0.280
Elkaloy D	0.18	0.23

(*b*) *Thermal Calculations.*—It is necessary that the cylindrical volume inclosed between two electrodes be raised to the welding heat. The heat required can be calculated from the following equation:

$$\text{Kilo-Calories} = \frac{d^2\pi}{4} \times 2s \times g \times T_w \times C$$

d = diameter of electrical tips
s = sheet thickness
g = specific gravity
c = specific heat
T_w = welding heat

The term $\frac{d^2\pi}{4} \times 2s \times g$ indicates the weight of the cylinder which is inclosed between the two electrodes. If this weight is multiplied by the specific heat and the welding temperature then the heat necessary for the welding can be calculated from the above formula. In addition to the calculated heat certain losses occur which must be taken into consideration.

(1) Conduction of the heat by the electrode. This is proportional to the electrode tip area multiplied by the temperature difference between the welding point and the electrode temperature and is also proportional to the length of time the electrodes are in contact with the work.

(2) Conduction by the welded sheets. This heat loss depends upon the diameter of the electrode tip and on the thickness of the sheet. It depends also on the temperature difference of the work, the weld heat and room temperature.

(3) Radiation losses. In Table 4 are given some of the more important properties of materials commonly welded.

Capacity of Welders

Any given size or capacity of welder is capable of handling a wide variety of stock thickness but there are many factors and conditions to be taken into consideration. Some of the factors governing this are: (1) Gage or thickness of sheet; (2) composition of material to be welded; (3) condition of material itself, whether clean, scaly, rough, etc.; (4) welding speed; (5) length of welder arms and distance between arms.

The shape of the job to be welded has an important effect on the output capacity of the welder. If steel extends into the throat of the welder this may act as a field choke thus reducing the secondary or welding current.

Table 4

Material	Electrical Resistivity Microhm ³/cm.	Electrical Conductivity % of Copper	Thermal Conductivity Cal./cm.²/cm./sec./deg. C.	Specific Heat Cal./%	Spec. Grav.	Melting Point °C.
Aluminum	2.83	60	0.504	0.214	2.71	660
Copper	1.724	100	0.918	0.092	8.9	1083
Nichrome	1.06	1.63	0.025	0.107	8.17	1390
Monel	50	3.45	0.05	0.127	8.80	1350
Lead	22	7.8	0.083	0.031	11.35	327
Armco Iron	10	17.2	0.161	0.107	7.86	1535
Zinc	6	28.5	0.265	0.093	6.7	420
Phos. Bronze	10	17.2	0.12	0.087	8.9	1050
Brass	9	19.1	0.22	0.094	8.40	935
Nickel Silver	33	5.2	0.07	0.094	8.45	1100
Nickel	10	17.2	0.142	0.105	8.86	1450
Stain. Steel	70	2.5	0.04	0.118	7.86	1400
Everdur	26	6.7	0.078	0.093	8.46	1019

Timing Devices

It has been found that short and accurately controlled timing with correspondingly high welding current results in superior welding which in many instances is otherwise impossible. This is because correct timing, especially when short, is the one factor most difficult to control with the usual welding equipment and, therefore, requires special timing devices. The most important factors in weld timers are: (1) accuracy, (2) flexible timing adjustment, (3) timers should operate direct from line voltage and (4) low maintenance cost.

Timing has become of particular importance in the welding of such materials as: (1) very light gage sheets, (2) dissimilar metals or alloys, (3) metal of high thermal conductivity, (4) stainless steels, (5) special alloys and (6) aluminum alloys and aluminum.

General Spot Welding Electrode Requirements

(*a*) *Electrical and Heat Conductivity*

It is essential that the electrical conductivity of a spot welding electrode be sufficiently high so that under correct operating conditions of pressure, etc., heating will occur at the joint of the materials to be welded and not between the electrode face and the stock to be welded; otherwise sticking of the electrode may occur. It is important that the heat conductivity be good so that the electrode can dissipate the heat generated during the welding operation.

(*b*) *Tensile Properties*

The yield point of electrode materials is important in resistance welding because the electrode material will flow plastically during the welding operation. The ability of the material to retain a reasonably high yield point at slightly elevated temperatures is important because of the rise in temperature to which the electrode face is subjected.

(*c*) *Electrode Design*

The design of a spot welding electrode will have a great deal to do with the life of the electrode during operation. As has been pointed out by investigators there is almost an unlimited number of designs of electrodes possible. In many cases the design will be dictated by the type of work to be welded. Very often, however, it is possible to make improvements by allowing for better heat distribution and heat dissipation in the solid metal parts of the tip.

(d) Cooling

Practice has shown the enormous importance of water cooling of spot welding electrodes. By this means alone the life of spot welding electrodes can be increased considerably because the temperature of the metal is kept below the annealing or recrystallization point. Some electrodes have been designed so that the water cooling has been brought to within a small fraction of an inch of the welding face; in other tips the cooling has been kept quite a distance away from the welding face. In some designs the water hole has been made so large that only a shell of the electrode remains. As is usual in most engineering problems a compromise is necessary.

(e) Welding Pressure

Another important factor in resistance welding and particularly with reference to the life of spot welding electrodes is the welding pressure. These pressures may vary from 5000 lb. per sq. in. to values as high as 50,000 to 60,000 lb. per sq. in. according to the type of material welded. If the welding pressure is maintained at a value higher than the yield point of the electrode material then the electrode will flow plastically or "mushroom." If this would occur at room temperature the cold work would harden the metal. In most cases, however, the temperature is near the softening point and no beneficial but rather detrimental effects result.

(f) Fundamental Requirements of Spot Welding Electrodes are high hardness, high yield point and high annealing temperature combined with high electrical and heat conductivity. The important property seems to be the ability of a welding electrode to retain its hardness and proportional limit at elevated temperatures.

In Table 5 are shown materials and combinations of material which can be successfully spot welded.

Table 5

METALS	ALUMINUM	ASCOLOY	BRASS	COPPER	GALVANIZED IRON	IRON	LEAD	MONEL	NICKEL	NICHROME	TIN PLATE	ZINC	PHOS. BRONZE	NICKEL SILVER
ALUMINUM	○										○	○		
ASCOLOY		○	○	○	○	○		○	○	○	○		○	○
BRASS		○	○	○	○	○		○	○	○	○	○	○	○
COPPER		○	○	○	○	○		○	○	○	○	○	○	○
GALVANIZED IRON		○	○	○	○	○	○	○	○	○	○		○	○
IRON		○	○	○	○	○		○	○	○	○		○	○
LEAD					○		○				○	○		○
MONEL		○	○	○	○	○		○	○	○	○		○	○
NICKEL		○	○	○	○	○		○	○	○	○		○	○
NICHROME		○	○	○	○	○		○	○	○	○		○	○
TIN PLATE	○	○	○	○	○	○	○	○	○	○	○		○	○
ZINC	○		○	○			○					○		
PHOS. BRONZE		○	○	○	○	○		○	○	○	○		○	○
NICKEL SILVER		○	○	○	○	○	○	○	○	○	○		○	○

The following sections cover the chemical composition, physical properties, resistance welding characteristics, electrode materials and strength of welded parts of the more important commercial alloys now being fabricated by resistance welding.

A. IRON (Low Carbon Steel)

a. Chemical Composition:

99 to 100% iron with small percentages of manganese, silicon, carbon, nickel, chromium, vanadium, molybdenum, etc.

b. Physical Properties:

1. Electrical Conductivity—10 to 17% (The conductivity depends upon the percentage of alloying elements present. For pure iron the conductivity will be approximately 17%.)
2. Melting Point—Approximately 1530° C.
3. Hardness—50 to 200 Brinell. (The hardness increases with carbon content percentage of alloying elements present and the amount of cold work.)

c. Resistance Welding Characteristics.—In the resistance welding of low carbon steel and iron the material is heated to the plastic range and the weld is effected by pressing the two pieces of heated material together. This is accomplished by the pressure on the electrodes. The pressure and temperature cause small deformations of crystals of the original sheets that will permit them to recrystallize. During the process of recrystallization the grains grow across the interfaces that separate the two sheets. This grain growth, therefore, is the fundamental phenomenon that welds the two pieces together. It is essential that the highest resistance occurs where the two metals are to be welded to each other. This resistance is closely associated with such factors as the quality of the sheet, carbon content, alloy content, surface conditions and the degree of oxidation of the surface of the sheets. In Table 6 the kva. required for the welding of smooth, clean, low carbon sheet are given.

Table 6

Gage	Spots per Min.	Kva. Required	Pressure
26	30	3	50 lb.—3/16 in. tip diam.
	120	12	90 " " " "
24	30	4	60 " " " "
	120	16	120 " " " "
22	30	4.5	70 " " " "
	120	18	130 " " " "
20	30	5	80 " " " "
	120	20	150 " " " "
18	30	6	140 " " " "
	120	24	220 " " " "
16	30	10	175 " " " "
	120	40	275 " " " "
14	30	15	220 " 1/4 in." "
	120	60	300 " " " "
12	30	20	275 " " " "
	120	80	500 " " " "
1/8 in.	30	30	280 " " " "
	120	120	550 " " " "
3/16 in.	20	50	450 " " " "
1/4 in.	20	100	600 " " " "

For oxidized sheets the kva. should be increased approximately 25%.

Smoothness of the surface of the sheets has a great effect on the temperature required to produce a satisfactory weld. Esser has reported that polished sheets can be welded at a temperature of 960° C. whereas this temperature must be raised to as high as 1300° C. to obtain a weld of maximum strength on rough sheets. In these experiments the welding pressure was held constant. If the pressure had been increased on the rough stock the weld could have been effected at a lower temperature.

In Table 6, pressures suggested are relatively light and do not reach more than 10,000 lb. per sq. in. when welding 120 spots per minute on 16 gage material. It should

be understood, however, that these values are for clean, flat steel and that for scaly stock the pressure must be increased sometimes as much as 50%.

In general, the regulation of pressure can be covered by the following rules: (1) Pressure should be increased with shorter welding time; (2) the pressure should be increased with heavier stock; (3) the pressure should be increased with scaly or rough stock.

Steel can be welded at lower temperatures with high pressure or at higher temperatures with low pressure. Laboratory tests have shown by raising the temperature from 915° C. to 1250° C. the pressure required at the higher temperature is approximately one-third that necessary at the lower temperature.

Spot welding becomes increasingly difficult as the thickness of the plate increases. As mentioned before, temperature and pressure are the important factors in welding, the latter causes deformation of the material while hot and therewith facilitating recrystallization which is the basic principle of resistance welding. The thicker the two sheets the more the total pressure will distribute itself over the surface of the contact of the two sheets without being concentrated in a definite area where the weld is to be made. It is assumed that the greatest portion of the current flows only where the sheets are in intimate contact. It can be readily seen that in the case of thin sheets the surface of the contact will be approximately the same as the electrode area and the current density will be high. As the sheet thickness increases the current density will drop off rapidly due to the increase in surface contact between the sheets and rather high currents will be necessary to make a good weld. Such currents increase the current density in the electrode and melting or burning may occur at the electrode point.

In connection with the selection of the proper pressure and current, accurate timing is suggested because it will greatly decrease the wear of the electrodes and will produce a more uniform weld. Excessive heat is to be avoided because it will tend to cause the formation of large columnar grains which are inherently weaker than fine equi-axed grains. Excessive heat also produces a brinelling effect, causing reduction of the cross section of the welded area.

d. Electrodes.—Hard, copper base alloy electrodes are almost universally used for the welding of low carbon steels. Alloy electrodes give from three to twenty times the number of spots possible with the now out-moded pure copper electrodes.

e. Strength of Welded Parts.—In sheet thickness up to 1/16 inch the strength is approximately 90% that of the original material. In heavier thicknesses, for example: 1/4 inch, the strength ranges from 60 to 80% that of the original material provided the proper welding conditions are used.

If the carbon content is above approximately 0.3% the sudden heating and cooling during the welding operation may cause hardening effects and therewith embrittlement of the welded zone and area adjacent to the welded zone.

Welds made in high carbon steel should be properly and carefully annealed. By using rather long welding times with relatively low current values the effect of annealing may be simulated to some extent. In general, however, it has been found that high carbon steels cannot be successfully fabricated by spot welding.

B. STAINLESS STEEL

a. Chemical Composition:

(1) 18% Chromium
8% Nickel
Small percentage of manganese, silicon
Balance—Iron

(2) 13% Chromium
Small percentage manganese and silicon
Balance—Iron

(3) 15 to 18% Chromium
Small percentage of manganese and silicon
Balance—Iron

(4) 25 to 30% Chromium
Small percentage of manganese and silicon
Balance—Iron

b. Physical Properties:

(1) Electrical Conductivity—2 to 5%
(2) Melting Point—1400 to 1480° C.
(3) Hardness—150 to 400 Brinell

c. Resistance Welding Characteristics.—The stainless steels generally used are those containing 18% chromium and 8% nickel. This material is used in the cold-worked condition in which the tensile strength is approximately 150,000 to 200,000 lb. per sq. in. If this material is heated above a critical temperature range, that is, approximately 900 to 1500° F., the strength is decreased to approximately 90,000 lb. per sq. in. If it is held for an appreciable length of time between 1100 and 1400° F. carbides will precipitate and material lose its resistance to corrosion and fatigue and to a large extent its ductility and resistance to impact. Exposure to these temperatures for times as short as one-half second may be detrimental under certain conditions. In order to minimize carbide precipitation and retain the high strength resulting from cold work it is necessary that very large welding currents be applied for extremely short periods of time. By thus eliminating the time of the application of heat the period of dwell of the heat within the material is made less than that which would impair the desirable characteristics of the welded portions.

The pressures used should be relatively high in order to insure good point contact and insure the desired rapid heat conduction from the interior of the weld out through the electrodes. The electrodes of course should be water-cooled in order to carry heat away as rapidly as possible. The pressure applied may be 50 to 100% above that used in the welding of ordinary steel. A good weld in stainless steel does not extend quite to the outer surface of the two adjacent sheets, its thickness being approximately from 50 to 80% of the total thickness of the two sheets being welded.

Two examples are given in Tables 7 and 8 to show the welding conditions used in the plant of a large fabricator of stainless steel.

Table 7

Gage, two thicknesses, each	0.010 in.
Diameter of electrode	3/16 in.
Area of resulting weld	0.00165 sq. in.
Total electrode pressure	75 lb.
Welding time	0.0083 sec.
Welding current	1472 amp.
Current density in welded area	894,000 amp./sq. in.

Table 8

Gage, two thicknesses, each	0.050 in.
Diameter of electrode	3/8 in.
Area of resulting weld	0.0143 sq. in.
Total electrode pressure	500 lb.
Welding time	0.0833 sec.
Welding current	4270 amp.
Current density in welded area	298,200 amp./sq. in.

d. Electrodes.—A hard copper base alloy is recommended for welding stainless steel.

e. Strength of Welded Parts.—As pointed out before, the strength of resistance welded stainless steel sheets is a function of the accuracy of welding. It is impossible to avoid some annealing of the cold work sheets and, therefore, the strength will be reduced somewhat. In general however, the strength can usually be maintained at a value above 80% that of the original tensile strength.

C. COATED STEEL

a. Chemical Composition:

(1) Terne Plate
Composition of Plate 80.25% Lead
18.00% Tin
1.50% Antimony

(2) Tin Plate
Composition of Plate: Pure Tin

(3) Galvanized Iron
Composition of Plate: Zinc

(4) Special Coatings
1. Chromium Plated Steel
2. Nickel Plated Steel
3. Copper Plated Steel
4. Steels with Non-Metallic Coatings such as: Light Enamels, Oxides, Carbon, etc.

b. Physical Properties:

(1) Core Material Steel:
Electrical Conductivity—10–17%
Melting Point—1530° C.
Hardness—100–200 Brinell

(2) Plate:

(*a*) Terne Plate—consisting mostly of lead:

Melting Point of Lead—327° C.
Boiling Point of Lead—1525–1870° C.
Electrical Conductivity—8–9%
Hardness—3–5 Brinell

(*b*) Tin Plate:

Melting Point—232° C.
Boiling Point—2400° C.
Electrical Conductivity—8%
Hardness—40 Brinell

(*c*) Galvanized Iron (Zinc):

Melting Point—420° C.
Boiling Point—905° C.
Electrical Conductivity—28%
Hardness—30–50 Brinell

c. Resistance Welding Characteristics.—All three types of coated steel can be spot welded. The coating metals become molten during the welding operation. The electrodes as well as the steel are therefore in contact with such metals as tin, lead and zinc while under pressure. Recent researches have shown that liquid metals will penetrate into solid metal under certain conditions. This penetration is, of course, a function of time and will not occur if the welding operation is relatively short. In most spot welding operations, therefore, little danger exists that liquid metals will penetrate into the sheet and cause embrittlement.

Because of the greater affinity of the coating material for the electrode metals the danger of intercrystallization penetration of the electrodes is much greater and it has been found that some electrode alloys are prone to such penetration. There exists also the danger that the liquid metals of the coating will form an alloy with the copper base electrodes. This will occur particularly if the welding face of the electrode gets hot. It is possible, for example, to dissolve a piece of copper by immersing it in molten tin or zinc, therefore, very effective water cooling should be used in the welding of coated steels in order to keep electrodes as cool as possible because in that condition their tendency to alloy or to intercrystallization penetration is greatly decreased.

In the welding of light gage galvanized sheets holes are sometimes burned through the sheets even when low currents are used. This is usually due to the pressure being too low. The zinc coating not only melts but becomes gaseous and causes an arc. This can be corrected by increasing the pressure and making sure that the pressure remains on the work after the current has stopped flowing. It is possible to weld galvanized sheet without seriously burning the coating. Under favorable conditions welds having thick coatings of zinc still left on the outside surfaces are being made in production.

Comparatively high currents are usually required to properly weld galvanized steel. Short welding times are essential for minimum surface disturbances, these ranging from 4 to 8 cycles, based on 60 cycle current. The increase in current input for welding galvanized steel should be approximately 25% higher than for welding of cold-rolled steel.

If the proper welding procedure is used, Terne Plate and Tin Plate are relatively easy to resistance weld. Welders having sufficient capacity to weld cold-rolled steel are entirely satisfactory for the welding of Terne Plate and Tin plate. Little or no trouble due to burning is experienced in the welding of these materials because of the relatively high boiling points of tin and lead.

Specially coated materials such as highly polished chromium plate, nickel plate, etc., are being welded to some extent. In welding these materials the same conditions prevail as in the welding of low carbon steel. It is often desirable to leave as little indication of a weld on the polished surface as possible. One method by which the polished surface may be protected from being marred is to use a large flat electrode against the polished surface and a dome shaped electrode on the other. The flat electrode should be polished so as to reduce surface marring to a minimum.

In the cases of steel having coatings which have relatively high electrical resistance, or which may be completely insulating, spot welding is difficult and special techniques are required such as increased pressure, increased voltage, removal of coatings, etc.

Inasmuch as the basic material of the above mentioned coated sheets is usually low carbon steel the same pressures can be used as are applied for welding steel.

d. Electrodes.—Alloys having high electrical conductivity and high hardness have been found to be suitable for welding coated sheet steels. Hard copper base electrodes are recommended.

The electrodes found most suitable for welding galvanized sheets have a spherical or ball point welding face and are generally classified as dome tips. More frequent dressings are required as compared to clean, mild steel. In dressing the electrodes the use of emery cloth is recommended for cleaning and removing any zinc, tin or lead deposit. A file is not recommended because the rough welding surface left from file dressing tends to cause pick-up of the coating from the steel. Under certain circumstances it might be advisable to redress the points in a lathe or a suitable machine which would give a smooth surface.

e. Strength of Welded Parts.—The strength of resistance welded coated steel sheets is approximately 90 to 100% that of the original material.

D. ALUMINUM

a. Chemical Composition:

90 to 100% Aluminum
Trace to 8% Copper
Trace to 1% Iron
Trace to 2% Nickel
Small percentage of manganese and silicon

b. Physical Properties:

1. Electrical Conductivity.—65% for pure aluminum; 35 to 40% for aluminum base alloys
2. Melting Point.—Approximately 660° C.
3. Hardness.—16 to 20 Brinell for pure aluminum; 80 to 120 Brinell for aluminim base alloys.

c. Resistance Welding Characteristics.—In spot and seam welding aluminum and its alloys the temperature must be increased to the point where the surfaces to be joined are actually in a molten condition yet the outside surface of the sheets contacting the electrode must remain practically cold. The basis of satisfactory spot welding aluminum or aluminum alloys is in the accurate control of all the variables. Equipment to be considered first class should have the following factors:

1. Suitable electrode design and maintenance.
2. Sufficient output in welding current.
3. The machine so designed as to prevent undesirable hammer-blow when the electrode pressure is applied.
4. Precision of the electrical timing of welding current. Table 9 gives a list of welding currents and welding pressures for various thicknesses of aluminum base alloys which have been found to produce good sound welds. In a very complete paper by C. W. Steward on welding of aluminum and aluminum alloys it has been reported that these variables can be changed considerably without effecting the quality of the weld. The essential characteristics, however, seem to be a relatively high pressure with a high current density for a relatively short time, that is, from 1 to 10 cycles.

Table 9

Thickness in Inches	Time in Cycles	Welding Current in Amp.	Welding Pressure in Lb.
0.020	1	15,000	200– 300
0.032	1–2	17,000	300– 400
0.051	2–3	19,000	400– 500
0.064	3–4	22,000	450– 600
0.081	5–6	26,000	550– 700
0.101	6–7	30,000	600– 900
0.125	8–9	35.000	800–1400

The best results are obtained by means of timing the current for each weld so as to provide a definite number of cycles. Various timers can be used but the best results are obtained with electronic devices. The current must be accurately synchronized with the application of pressure.

Ordinarily no surface cleaning or preparation is required for spot welding aluminum and some of the more common alloys, however, it has been found that abraiding the surfaces with sand paper will produce a uniformly stronger and better weld.

(*d*) *Electrodes.*—Ordinary pure copper is unsatisfactory or electrodes as the high unit pressures employed cause rapid deformation. Best results are obtained by using hard, high conductivity copper base alloy electrodes with a welding face machined to a flat cone at an angle of 7°. If it is necessary to maintain a smooth surface on one of the sheets a flat electrode may be used in conjunction with a cone shaped electrode. The reason for the angle of approximately 7° is that an electrode of this shape will permit the proper rate of penetration of the electrodes into the metal as the weld is made. Thus, as the welding progresses the area of the contact of the electrodes with the metal is increased. The theoretical explanation seems to be that the electrodes make an angle with the plane of compression equal to the angle of friction between the material being compressed and the electrodes. This angle for most metals in contact with another metal varies between 8 and 12°, therefore, electrodes of a conical shape with about the indicated angle should produce a uniform stress distribution and a uniform deformation.

(*e*) *Strength of Welded Parts.*—In heat treated aluminum alloys such as duraluminum the strength shows a linear relation to the sheet thickness both in shear and tension on sheets up to approximately $^3/_{64}$ inch. Above this thickness this relationship drops off due to the longer time and the higher temperature necessary. If the welded sheets are later heat treated the strength of the spot increases to almost the strength of the original sheet.

E. NICKEL AND NICKEL ALLOYS

(*a*) *Chemical Composition:*

(1) Nickel: 99 + % Nickel
(2) Monel Metal: 30% Copper
1% Manganese
1% Iron
68% Nickel

(*b*) *Physical Properties:*

(1) Electrical Conductivity.—(*a*) Nickel: 15% (highest purity nickel up to 20%); (*b*) Monel: 4%
(2) Melting Point.—(*a*) Nickel: 1440° C.; (*b*) Monel: 1330°–1350° C.
(3) Hardness.—(*a*) Nickel-annealed: 75–95 Brinell; nickel-cold worked: up to 150 Brinell; (*b*) Monel-annealed: 100 Brinell; Monel-cold worked: up to 225 Brinell

(*c*) *Resistance Welding Characteristics.*—Monel metal and pure nickel can be successfully resistance welded. The results of spot welding on Monel metal are not quite as good as on steel, as it seems more difficult to avoid a brittle spot weld, and considerable skill and experience are required to avoid burning at the spot weld. These difficulties are overcome with accurate timing. In spot welding care must be taken that the pressure is on the metal before current passes through the work. The work should be supported by a jig so that no bending can occur at the heated sections.

There is a peculiarity manifested in high nickel alloys that is perhaps not so marked in other metals, namely: a hot, short range, which means a range of low tensile strength and brittleness between the temperatures of 1450–1650° F. Both above and below this hot, short range these alloys regain normal strength and ductility. For this reason, expansion and contraction must be taken into account to see that there are no undue stresses set up or existent while the weld metal and immediately adjacent metal is passing through the hot, short range as the weld is cooling.

Spot welding should be done very quickly. It requires about half the time and twice the current to spot weld Monel metal than is required for steel of the same thickness.

Monel metal can be seam welded successfully. The practical limit for electric seam welds on Monel metal is Gage 18 (0.050) and lighter. The work must be well supported under the seam welding machine so that the Monel metal at the line of the weld and immediately ad-

jacent to it cannot be bent during the time the weld is made and until the metal has cooled below 800° F.

Any movement of the metal at a red heat will weaken it, and even if fractures do not appear at once the probable result will be cracks occurring along the line of the weld after the job is in service.

Spot welding of plates thicker than $^1/_4$ inch is impractical. The pressure required is approximately $^1/_2$ to $^2/_3$ that used in welding iron and steel. The pressure, of course, will depend on the thickness of the materials welded and on the speed of welding. Under every condition the lightest allowable pressure should be used.

(*d*) *Electrodes.*—It was pointed out before that Monel metal has a very low conductivity, while nickel has a rather high electrical conductivity. It is, therefore, necessary that high conductivity alloys be used for welding of pure nickel.

(*e*) *Strength of Resistance Welded Parts.*—With proper welding conditions and good support, annealed Monel metal and nickel will retain almost 100% of their strength, while cold rolled material will retain approximately 80% of the strength of the original sheet. The strength is a function of the thickness of the plate to be welded.

F. COPPER, BRASSES AND BRONZES

(*a*) and (*b*) *Chemical Composition and Physical Properties.*—See Table 10.

(*c*) *Resistance Welding Characteristics.*—The resistance welding characteristics of copper and copper base alloys is approximately inversely proportional to the electrical and heat conductivity. Copper alloys, in general, do not possess a wide temperature range within which they can be welded. The copper alloy must actually be melted to obtain a satisfactory weld. Because of the high latent heated fusion of most copper alloys rather high currents are required.

In the case of low zinc brasses, commercial bronzes and other special copper alloys a welding machine having a capacity of 150 kva. is usually required.

In Table 10 various copper alloys are listed, giving the approximate composition, melting point, electrical and thermal conductivity, tensile strength and the resistance weldability ratings. The letter "A" indicates the alloys that have excellent resistance welding characteristics; "B" indicates good resistance welding characteristics; "C" fair; and "D" poor. Of all the copper alloys those containing approximately 3% silicon with small percentages of manganese, zinc or tin, would be easiest to weld. Copper alloyed with silicon alone forms under fusion welding heat a refractory scale. Modified with manganese and to a lesser extent with small percentages of zinc and tin the scale formed at the welding heat is in the nature of a transparent fusible glass which if allowed to harden becomes an excellent dielectric which may interfere with the resistance welding operation. It is, therefore, important that the surface of the silicon type copper alloys be very clean before resistance welding is attempted.

In the welding of various brasses a considerable amount of zinc may be volatilized. This can be kept to a minimum however by very careful control of pressure, current and timing. If an unforseen change occurs in the welding procedure such as an accumulation of scale or dirt on the electrodes or between the sheets the high electrical heat energy may vaporize the zinc momentarily and result in a hole or burned spot in the sheets.

Copper has been successfully spot-welded and seam-welded up to thicknesses of approximately $^1/_{16}$ inch, however, considerable difficulty is encountered and with the exception of a few more or less minor applications the resistance welding of copper is not being done on a commercially large scale.

The low electrical resistance of copper presents difficulties in creating sufficient heat between the two sheets. Furthermore, the high thermal conductivity of copper tends to dissipate the heat too rapidly.

Welding of pure copper may be facilitated somewhat by tinning or plating the inner surfaces of the sheets so as to create a higher resistance at the point to be welded.

Table 11 shows the capacity recommended by one of the larger resistance welding companies as being correct for various copper alloys. This table is probably only approximate and gives the kva. capacity for spot and

Table 10

Name	Approximate Composition,* %			Melting Point		Conductivity Elec. %		Tensile Strength Psi		Resistance Weldability Rating
				Deg. C.	Deg. F.	I.A.C.S.	Thermal	Soft	Cold-Rolled	
	Mn	Si	Sn							
Everdur A	1	3		1019	1866	6.7	0.08	56000	90000	A
	Zinc									
Olympic Bronze	1	3		1060	1880	7.0	0.08	56000	90000	A
Herculoy	1.5	3.25	0.5	1023	1870	8.0	0.10	60000	95000	A
Duronze		3		1060	1880	7.8	..	55000	85000	A
		Ni								
Nickel-Silver A	20	18		1110	2030	5.9	0.08	58000	90000	A
	Al									
5% Al Bz	5	...		1060	1940	17.7	0.18	52000	90000	B
8% Al Bz	8	...		1040	1904	14.8	0.16	60000	100000	B
	Be									
Beryllium Cu	1.5	0.5		915	1679	17	...	70000	118000	B
Beryllium Cu Heat Treated	1.5	0.5		915	1679	23	0.20	....	180000	B
	Zinc									
Red Brass 80	20	...		1000	1832	32	0.34	43000	80000	B
		Tin								
Coe Bronze	..	10.5		1000	1832	10.6	0.12	60000	100000	B
2:1 Brass	34	...		920	1688	26.0	0.29	46000	70000	B
Muntz Metal	40	...		905	1661	28.6	0.30	55000	.....	C
Tobin Bronze	40	0.75		885	1625	25.0	0.28	54000	75000	C
Red Brass 85	15	...		1020	1868	37.0	0.38	42000	70000	C
Commercial Bronze	10	...		1045	1913	41.0	0.45	37000	65000	D
	Phos.	Oxygen								
Deoxidized Copper	Trace	0.00		1083	1981	85	..	33000	50000	D
Copper	..	0.05		1083	1981	100	0.92	32000	50000	D

* Balance—mostly Copper.

seam welding as a function of the electrical conductivity of alloys in the form of sheets 0.040 inch thick.

Table 11

Conductivity	Seam Welding	Spot Welding
50	240	150
40	200	125
30	160	100
20	125	80
10	95	60
5	75	40

The electrode pressure found most suitable for welding copper or copper base alloys is approximately one-half that required for steel. A pressure of 8000 psi on the electrode face was found to be satisfactory.

(*d*) *Electrodes.*—High conductivity, high hardness copper base alloys are recommended for welding the medium and low conductivity copper base alloys of the silicon-manganese, silicon-zinc, aluminum-bronze, high zinc type. For copper and the alloys falling in the range where the conductivity is relatively high an alloy of low conductivity has given satisfactory results, although some heating occurs between the sheet and the welding face of the electrode.

In general, however, it is well to use an accurate timing control with these low conductivity electrodes. This alloy is used in the form of a thin facing or insert silver brazed to a copper or copper alloy backing. A composite construction helps dissipate the heat generated between the surface of the sheet and the welding face of the electrode.

(*e*) *Strength of Welded Parts.*—The strength of spot welded annealed brasses and bronzes is approximately 90 to 100%. The strength of cold-worked brasses and bronzes will vary from approximately 60 to 80% that of the ultimate tensile of the cold-rolled material. Age or precipitation hardened alloys such as beryllium-copper may drop as low as 40% that of the original. The major portion of the original strength can be regained by suitable heat treatment.

The strength of welded pure copper is usually quite low. In some welding operations it is possible to make welds which when tested to destruction will pull a slug or hole in the one sheet.

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Sensitivity to Welding Cracks*

THIS excellent article by Mr. Zeyen of the staff of Krupp-Essen, Germany, is along the same lines of two earlier articles (*Stahl u. Eisen*, **55,** 1935, 902; *Techn. Mitt. Krupp*, **3** (4), 1935, 176–188) by him, translated by the Fundamental Research Committee and available to members on request.

In his latest article Mr. Zeyen confines attention to cracking in high strength sheet (medium-carbon, carbon-manganese and chromium-molybdenum, tensile strengths 80,000–110,000 psi, 0.047 inch thick, oxyacetylene welding). Each of the following tests is always used to evaluate the sensitivity of such sheet to cracking during welding. First, melting the surface of a square sheet along a straight line from an edge toward the center without using filler rod. Second, depositing a bead of weld metal on the sheet using the customary filler rod.

* Translated by Dr. G. E. Claussen, Research Assistant, Fundamental Research Committee.

(Abstracts from an article of the above title by K. L. Zeyen in *Z. VDI.*, **80** (32), 969–973, Aug. 8, 1936.)

Third, welding a T joint or angle. In all tests the total length of cracks revealed by etching is taken as the degree of sensitivity to cracking.

Another type of test employs two plates rigidly gripped and then butt-welded together. The cracks are detected by first etching the entire specimen for one hour in alcoholic picric acid and then cracking open the weld. The acid gives all cracks a distinctive yellow color. Although the acid is more reliable than simply noting temper-colored areas in the fracture, the acid cannot locate cracks that do not extend to the surface of the specimen. The percentage of the total lengths (not area) of the weld occupied by cracks as outlined by acid or temper colors is called the crack sensitivity. For the sake of simplicity the depth of the cracks is not considered. The rigidly gripped plate test is becoming more and more popular. But no method yet developed for evaluating welding cracks is suitable for inclusion in specifications.

In addition to the effects of incorrect welding sequence and heat treatment, and improper torch manipulation on crack sensitivity, the steel-making methods employed in manufacturing chromium-molybdenum steel are also factors; for example: raw materials (pig iron, ore, scrap, alloy addition), melting process (basic or acid, open-hearth or electric), refining (slags and agitation).

Observations have shown that chromium-molybdenum steel made in the open hearth has a greater tendency to cracking during welding than electric furnace steel of the same composition. A low maximum content of phosphorus and sulphur should be included in the specified analysis for aircraft sheet and tubing, which should only be made by the electric furnace process.

To show how important the type of steel making process can be, Mr. Zeyen cites an open-hearth melt of chromium-molybdenum steel which had been given a special treatment in the open hearth. The melt had an extraordinarily high carbon and manganese content, above that permissible for aircraft tubing. In ordinary open-hearth melts of chromium-molybdenum steel the crack sensitivity increases with increase of alloy content and especially of carbon. Nevertheless, the special open-hearth melt with decidedly unfavorable composition had a far lower crack sensitivity as determined by all methods than ordinary open-hearth melts of more satisfactory composition. It has been impossible up to the present to obtain much experience with the new type of open-hearth steel because most aircraft steel is specified as an electric furnace product.

Special treatment of chromium-molybdenum steels in the electric furnace has produced a steel which is completely insensitive to cracking during welding, even when tested under the most severe conditions. Numerical results are given by K. L. Zeyen, *Techn. Mitt. Krupp*, **4** (4), 115, 1936.

Welding cracks in chromium-molybdenum steels are intercrystalline. A micrograph clearly shows that welding cracks proceed along grain boundaries.

Question and Answer Column

Stress-Relieving

Question

THE AMERICAN WELDING SOCIETY received the following inquiry:

"We have been informed that several large welding concerns in such cases as welded machinery frames, structural shop welds and similar things that do not come directly under the A. S. M. E. Code for unfired pressure vessels, are stress-relieving at 900° F. instead of 1100° F. as specified in the A. S. M. E. Code.

"The practice seems reasonable because if average weld material has a tensile strength of 70,000 lb. per sq. in. with a yield point of 0.45 or 31,500 lb. per sq. in. it should be satisfactory to reduce the strength to slightly below this point which would happen at about 900° F. when the strength has decreased to about 0.35 to 0.40 of the original strength.

"Any information you can give us on the subject will be gratefully received."

Answer

EDITORS NOTE: *We take pleasure in publishing the following reply received from Mr. Charles H. Jennings and would like further communications on the subject.*

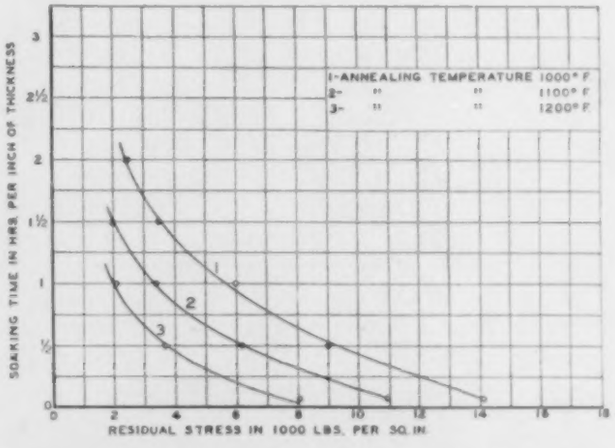
Charles H. Jennings,

Westinghouse Electric & Manufacturing Company:

"I know of no organization that has stress-relieving welded structures at 900° F. This does not mean, however, that low temperature strain annealing cannot be done.

"The theory of stress-relief by annealing is dependent upon the lowering of the yield point of steels at elevated temperatures and the plastic flow or creep of steels under stress at high temperatures. The higher the annealing temperatures, the lower the yield point becomes and the more pronounced is the effect of creep. As a result, the value of the residual stresses remaining in a welded structure after strain annealing is dependent upon the annealing temperature and the soaking time (time the structure is held at the annealing temperature).

"The writer published a paper entitled 'The Relief of Welding Strains by Annealing,' in the September 1931 issue of the Journal of the AMERICAN WELDING SOCIETY in which the effect of various annealing temperatures and soaking times on the relief of residual stresses are given.



Curves giving these results are shown in the accompanying figure. Extrapolating the results obtained from annealing temperatures of 1000, 1100 and 1200° F., it is seen that the residual stresses remaining in a structure after annealing at 900° F. for different periods of time would be:

Soaking Time	Final Residual Stress
1/2 hr./inch of thickness	14000 lb./sq. inch
1 hr./inch of thickness	9500 lb./sq. inch
1 1/2 hr./inch of thickness	6000 lb./sq. inch
2 hrs./inch of thickness	4000 lb./sq. inch

"From the previous data, it is evident that a wide range of strain annealing temperatures can be used, but that the higher temperatures produce more complete strain relief in a shorter period of soaking time. If the remaining residual stresses in structure are not required to be lower than 4000 to 6000 lb/in.^{2}, an annealing temperature of 900° F. would probably be satisfactory if a soaking time of 1 1/2 to 2 hours per inch of thickness is used."

Report on Some Impact Tests of Fillet Welds*

By WENDELL F. HESS†

IN October 1934 at the New York meeting of the fundamental research committee, Mr. Andrew Vogel proposed a method of testing fillet welds using the Charpy impact testing machine.** Three objects of such a test were stated in Mr. Vogel's report somewhat as follows:

(1) A measure in foot pounds of the resistance to failure by impact applied transverse to a fillet weld.

(2) Determination of penetration into the root of the weld.

(3) An opportunity for visual inspection of the fractured surface.

Figure 1 shows the shape of the specimen and the point of application of the impact load. The welded assembly is cut into 1/2-inch strips. A specimen holder is designed to clamp the longer bar of the specimen and bolt into the pendulum of the Charpy machine. A bar for engaging the horns of the machine and applying the load is clamped on the other leg of the specimen.

At R.P.I., during the past two years, tests have been made under the direction of Prof. Lawson and myself by Mr. A. F. Poole and Mr. A. E. Munier, senior students

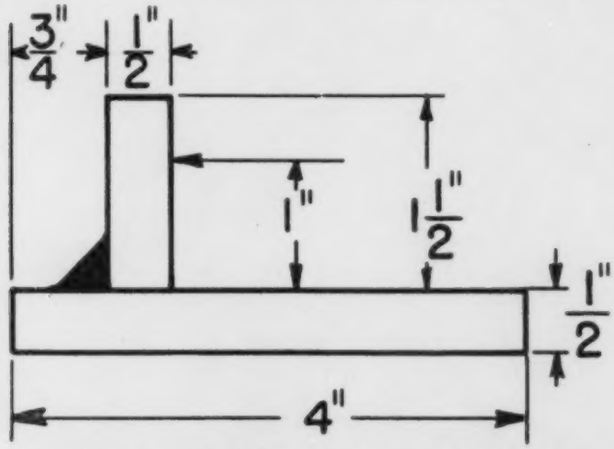


Fig. 1—A 1/2-inch x 1 1/2-inch Bar Is Welded to a 1/2-inch by 4-inch Bar with a 3/8-inch Fillet Weld. These Bars Are Usually 12 Inches Long, Thus Providing Several Specimens, as the Welded Assembly Is Cut into 1/2-inch Strips

* Presented at Fundamental Research Commitee Conference, in Cleveland, Oct. 20, 1936.

** See "Proposed Impact Test Specimen," A. Vogel, JOURNAL AMERICAN WELDING SOCIETY Vol. 15, No. 9, Sept. 1936, Research Committee Supplement page 11.

† Assistant Professor of Electrical Engineering and Physics, Rensselaer Polytechnic Institute.

in civil engineering, using the specimen proposed by Mr. Vogel.

Our studies show the proposed impact test to be very useful and informative as to the character of the *weld*, the *welder* and the *parent metal*. The low cost of specimen preparation makes it particularly attractive.

Being an impact test it strongly emphasizes the marked superiority of covered electrode over bare wire welding. Values of absorbed energy for impact fracture run consistently three times higher for good covered electrode than for bare wire. Since failure occurs through the throat section by bending, the depth of the throat section which includes the penetration at the root of the weld, is vitally important. The resisting moment of this section should be approximately proportional to the square of the depth of the throat section which means that slight variations in penetration at the root of the weld will cause large variations in the results of the tests. This explains the difficulty of getting consistent results from any but the best welders.

The ultimate fiber stress in tension is developed at the root of the weld which makes the quality of this metal of the greatest importance. This fact coupled with the effect of penetration depth combine to make this test extremely sensitive to this portion of the weld. A type of electrode designed for deep penetration should show up well in this type of test.

As a means of determining the ability of welders the test possesses advantages. The ability to secure good fusion at the root of the weld and to do it consistently is readily determined, as mentioned above. An excellent opportunity for visual inspection of the interior of the weld is obtained. A numerical rating is made available. Perhaps the largest contributing factor to the desirability of this specimen as a test for welders is the low cost of the specimen and the simplicity of the test, providing a Charpy impact machine is available.

It was mentioned above that this test is informative with regard to the parent metal. In making our tests, different groups were made with different lots of steel purchased at intervals from different concerns. In one group of tests the failures occurred by peeling of a layer of parent metal with the weld, or by tearing out of a section of the parent metal. A macroscopic etch showed distinct laminations in the parent metal as though it had been made by rolling slabs together. A microscopic etch showed that not only was the material laminated but that it was made of a layer of slaggy iron on top of a layer of medium carbon steel. The welds had been made against the layer of iron which was about a sixteenth of an inch thick and this layer either peeled off along the boundary between the iron and steel or a section of it tore out with the weld metal. All of these tests gave low energy values and very inconsistent results as was to be expected from the type of failure.

In another group of tests tearing out of the welds occurred at very low energy values. The steel used in this group showed no lamination under the macro etch, but under the micro examination showed a slaggy layer at the base of the weld, indicating a poor steel for welding.

With better quality steel the failures regularly occurred through the throat section, and the energy values became consistent when the welds were made by expert welders.

As an extension to the test it was decided to study the time required to fracture the specimen. To do this a simple circuit using the time required to charge a condenser was set up to measure the time to one hundred thousandth of a second. Since the times involved in our tests were of the order of thousandths of a second, this method gave satisfactory precision. The time measured

was from the striking of the horns of the machine to the completion of the fracture of the specimen.

The determination of the time required to fracture the specimen makes possible, in combination with the energy absorbed as determined by the Charpy machine, a calculation of the average force required to fracture the weld. Then if it is considered that the section fails by bending through the throat section with a neutral axis at the center, we can determine the approximate ultimate fiber stress. This latter is, however, of little value except as to order of magnitude because we do not know the force at the instant of failure, but only the average force during failure. That we have a neutral axis at the center is not shown by observation of the fracture because this proceeds as a tear across the section and the neutral axis shifts toward the compression side. However, a celluloid model for photoelastic study indicates that a neutral axis does exist at the center.

Mr. Munier's work indicates that the time required to fracture the covered electrode specimen was greater than that for bare electrodes, but not so much greater as the respective energies required for fracture. This shows that the average force required to fracture was also higher for covered electrode weld than for bare wire. From the best data we have, which is not sufficiently extensive, it appears that the force required to fracture, and consequently the ultimate resisting moment and fiber stress, is of the order of 25% greater for the covered electrode than for bare wire welding for quarter inch fillet welds. This result is not in agreement with Mr. Poole's work in this respect but we have reason to believe the discrepancy is due to a slight difference in experimental technique which introduced errors in time determination in the earlier work.

As a further extension of the test, in order to find out whether the forces we were calculating had any real significance as ultimate values for the weld at least in the range of available energies and velocities we were using, we decided to change the available energy. In order to do this a linkage was made by which we could secure four different values of available energy from full value to one-half this amount. For our most consistent data which was for quarter inch fillet welds made with covered electrode, the time required to fracture with different amounts of available energy varied inversely with the average velocity of the pendulum during fracture. Also, the absorbed energies remained practically constant with different amounts of available energy. The average force required to fracture, therefore, remains constant for this range of available energy and striking velocity.

It will be interesting in future work to make fairly careful measurements of the depth of the throat section so that we may calculate the average breaking stresses at the extreme fiber. These values might then be more consistent than the values of energy or average breaking force, since the test is so sensitive to the depth of the throat section.

The average breaking force calculations are made on the basis of the following simple relation:

$$\text{Average Force} = \frac{\text{Work Absorbed in Fracture}}{\text{Average Velocity} \times \text{Time}}$$

The average extreme fiber stress for fracture would be calculated as for bending in a beam.

$$\text{Stress} = \frac{6 \text{ Moment in inch pounds of average force}}{bd^2}$$

where b = width of throat section
d = depth of throat section

Discussion of Paper* by Dr. Jacobus on "Recent Practice in Fusion Welded Boiler Drums"†

Mr. F. L. THRUPP.—I notice that this fusion welding can be used for plates up to five inches and I am wondering whether a testing of the weldings is only carried out when the run is complete, that is for the whole thickness having to be traversed by X-rays, or whether tests are carried out after each weld in which case I presume it is necessary to have your inspecting engineer constantly in attendance, and I am wondering whether this is the actual practice.

Dr. D. S. JACOBUS (The Babcock & Wilcox Company).—The X-ray examination is made when the welding is completed. The Bucky grid referred to in my paper is especially useful in examining thick welds. The inspector may examine the weld at any time to judge the quality of the work while in progress.

MR. THRUPP.—I happened to have been instrumental in the placing of boilers with fusion welded drums in Italy before they had been used anywhere else in Europe. In the beginning especially, there was some delay in getting the drums because of the necessity of examining each layer, and I imagine that with the big thicknesses it would necessitate long exposures and that might delay the boiler drums. I am wondering whether any technique has been developed by which this delay would be diminished in the future.

DR. JACOBUS.—There are no X-rays for each individual layer, but in some cases two exposures may be made for the heavier plates. The X-ray technique is getting better and better and does not lead to undue delay. The development of X-ray tubes for 400,000 volts mentioned in my paper reduced the exposure time for thick welds.

MR. THRUPP.—I fancy that if a fault is found in a very thick weld, it takes a long time to cut it out.

DR. JACOBUS.—The faulty part is readily removed and rewelded and after this is done the drum is stress-relieved.

DR. F. ENGLERT (Maschinefabrik, Germany).—I would like to raise a question. When you find a defect in a weld, and say you have to remove that defect, my understanding is that it is really not difficult, as might be thought from the remarks. The weld is simply put in by machinery and taken out by machinery and it takes only a very short time.

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* Presented at Round-Table Conference of Third World Power Conference, held in Philadelphia, Pa., September 24, 1936.

† Published in October 1936 issue of AMERICAN WELDING SOCIETY JOURNAL.

DR. JACOBUS.—You are correct. It may require somewhat more skill to fill in a short length of weld to avoid undue strains than in laying in a long weld, but with the proper technique the defective part of the weld can be readily removed and replaced.

MR. W. E. CALDWELL (New York Edison Company).—What thickness of welding material can be obtained at one pass?

DR. JACOBUS.—In electric arc fusion welding the layers are usually about $^1/_8$ inch thick, but this is not the limit that may be used.

MR. CALDWELL.—Even in a five-inch plate, probably an eighth of an inch per layer?

DR. JACOBUS.—About that.

DR. ERNST LUPBERGER (Association of Large Boiler Owners).—The excellent paper by Dr. Jacobus has been extremely interesting to us and I should like to make a few remarks concerning our experience in this matter.

We also do not use riveted drums any more. Drums welded with water gas and electrically welded drums are used in great numbers for pressures up to about 850 pounds. Some large steel works have been permitted to figure the stresses in welded joints at the 0.9 fold of the stresses permissible for the plates.

It is customary not only to relieve the stresses in the drums at about 1100° F., but to anneal (normalize) them at about 1700° F. They are being made of low-carbon steel or an alloy steel containing 0.3% Mo (tensile strength up to 70,000 pounds per sq. in.).

For pressures of over 900 pounds we prefer to use forged drums, made of steel having a tensile strength of up to 100,000 pounds per sq. in. We can in consequence use lower wall thicknesses, which means lighter drums. Fusion welded drums are usually subjected to X-ray tests. The X-rayed tubes are placed during the tests inside of the boiler drum and they are completely encased in order to protect the operator against the X-rays. The cables (200,000 volts) are being introduced through the manhole. One can use these tubes also to test the welded joints of old boilers which have been in operation several years. We prefer the method of placing the X-ray tube inside of the drum, because in that case the direction of the rays follows the contact surface between the drum plates and the weld, and, therefore, the faults in the contact face appear darker on the film and are better visible.

Electrically welded drums of any size can be manufactured in Germany. For heat accumulators one has used electrically welded drums up to 70 feet long and having $10^1/_2$ feet diameter. Forged drums have been made up to 60 feet long and $5^1/_2$ feet diameter.

MR. PERRY CASSIDY (Babcock & Wilcox Company).—Do you permit fusion welding on high-tension forged drums?

DR. LUPBERGER.—We use fusion-welded drums only with low carbon steel and low molybdenum up to 70,000 pounds per square inch, and for high-tensile strength drums we used only forged drums.

MR. CASSIDY.—You don't permit the welding of outer connections or structural supports on these forged drums?

DR. LUPBERGER.—The connections are only welded for tightening; we divide all connections into small tubes in a large drum and the small tubes connect to the superheater. We don't use one large connection; we use about ten or twenty or thirty very small connections. There is no necessity to reinforce any of these holes because they are not larger than the few holes for the other tubes which are put into the drum. I believe that this is about the same as is done in America.

MR. CASSIDY.—You mentioned one of the limitations was in obtaining X-rays. Up to what thickness do you X-ray?

DR. LUPBERGER.—We make X-ray tests up to thicknesses of about three or four inches.

We have provided a central institute in Berlin for X-ray tests, and this institute has made great progress, but we believe that for such heavy wall thickness we are not able to find small cracks. We, therefore, have also developed an electrical magnetic method. We have a different system and use no dry powder. We use oiled magnetic powder and we spray it over the drum which in a short time makes a very fine coating. We use a powder in a clean oil of a green color.

DR. JACOBUS.—Dr. Lupberger asked about the limitations of the carbon content in the steel plates used in this country. The general practice is to follow the A. S. M. E. Boiler Code, and in that Code the upper limit is specified as 0.35 per cent, based on a check analysis. In much of the steel used the minimum of the specified range of tensile strength is 55,000 lb. per sq. in., and the highest strength steel that is sanctioned in the Code for fusion welding is 70,000 lb. per sq. in., this being a plain carbon steel in which the manganese content is no greater than 0.9 per cent, or one containing from 0.25 to 0.6 per cent of molybdenum with lower carbon content.

Tubes of chromium and nickel steel are welded end to end by the electric-resistance method.

CHAIRMAN.—Are there any other questions or discussion?

MR. CALDWELL.—I would like to ask Dr. Jacobus what would be the difference in the allowable stress for, let us say, a forged drum of the same material instead of a fusion welded drum of the same size?

DR. JACOBUS.—In a seamless forged drum the allowable stress would be 100 per cent of the minimum of the specified range of tensile strength of the steel. For a boiler drum with a fusion welded longitudinal joint built in accordance with the A. S. M. E. Code it would be 90 per cent. For an unfired pressure vessel built under the Joint A. P. I.-A. S. M. E. Code it might be as high as 95 per cent.

MR. CALDWELL.—I am not so much interested from the standpoint of boiler drums as I am from the large high-pressure piping over which we argue about repeatedly concerning the strength of a flanged pipe as compared with a fusion-welded pipe of sixteen-inches or larger. With a flanged pipe of large size for a high pressure the length of the sections is limited by the weight of the ingot which necessitates a great many circumferential seams very closely spaced as against a fusion-welded pipe which may have greater length with one longitudinal joint.

DR. JACOBUS.—There is an A. S. T. M. specification for pipe 18 inches in outside diameter and over with fusion welded longitudinal joints which requires the welding to meet the A. S. M. E. Code requirements for boiler drums, including X-ray examination and stress-relieving. This pipe should be as safe for use as fusion welded boiler drums. Much seamless piping is now fusion welded end to end and this practice is rapidly advancing.

Discussion of Article by Messrs. Rooke, Saacke and Kugler* on "Multi-Layer Oxyacetylene Pipe Welding"

By G. W. PLINKE†

IT IS difficult to supply any additional information to a subject that has been so carefully thought out and prepared as that contained in the paper entitled "Multi-Layer Oxyacetylene Pipe Welding" and presented by Messrs. Rooke, Saacke and Kugler at the annual meeting of the AMERICAN WELDING SOCIETY in Cleveland. However, it has been our privilege to learn the peculiarities and characteristics of numerous modifications of the multi-layer method of gas welding through many years of welding experience obtained in the fabrication of pressure vessels in our shop.

On pressure vessel welding, where the vessel can be placed on rolls and turned without difficulty, it has usually been our practice to apply several continuous layers of weld metal on all thicknesses 3/8 inch and above, the number of layers depending upon the thickness of the vessel being welded. On pipe work where the section was long and difficult to handle, the step-method of gas welding by depositing multiple layers of weld metal was used, but only in layers of short length. By this latter method difficulty was experienced because of stress concentration and the section would get out of alignment even though the joint had been securely tack welded in numerous places around the circumference.

We found that better results were secured on thick wall pipe by first applying a continuous layer of weld metal which penetrated well to the root of the vee. Then the balance of the vee groove was welded by the step method with layers of short length. There was less distortion by welding the pipe in this manner, however; it was never practiced to any general extent as we found that better alignment could be obtained by applying several layers of continuous welds.

Pressure vessel welding has advantages over pipe welding in that the vessel can be readily revolved during the welding and also because, in the majority of cases, being able to get on the inside of the shell through a manhole, a double vee type groove can be used on pressure vessels having thick walls. Continuous layers of weld metal are always applied. The first layer which is considered only as a seal weld is partially chipped out from the opposite side after the one side has been completely welded. Only sufficient metal is chipped out to insure getting down to good clean metal. This opposite side of the groove is then properly prepared and is welded by the continuous layer method using as many layers as necessary to completely fill the groove.

Slight peening of the layers of weld metal has proved beneficial in relieving stresses and preventing distortion and sufficient benefit has been derived to warrant making it a standard practice.

There is hardly any doubt but that greater ductility is obtained when the weld metal is applied in layers either by the continuous or step method since the metal obtains the benefit of the heat treatment from each subsequent layer applied, thereby causing considerable grain refinement in the weld metal. During our investigations to secure greater ductility, we have tried to refine the metal of the last applied layer of weld by passing the torch over it immediately after the welding operation. Some benefit was obtained but the cost and additional time was such that the practice was not continued. However, on some classes of work, sufficient good may be accomplished to warrant its use.

Using the continuous multi-layer method of oxyacetylene welding, we have always been able to obtain physical qualities in the weld metal which were well above any obtained by the single layer method. Ductility as determined by the bend test ranged from 20 to 45%. Other qualities such as tensile strength, impact and density were also good. The nick-break test revealed weld metal that was entirely free from porosity, slag and non-fusion.

However, when test specimens were prepared in an attempt to pass the A. S. M. E. Code requirements as set forth in paragraph U-68 of the Unfired Pressure Vessel Code and paragraph P-101 of the Power Boiler Code, we found ductility was lacking in the 0.505-inch all-weld tensile test. Elongation ranging from 12 to 19% was obtained consistently, but regardless of the number of layers of weld used or the manner in which they were applied, elongation better than 20% was rarely obtained.

In order to prove this point, four separate plates were welded, each by different methods and designated as plates *A*, *B*, *C* and *D*. Each plate was 5/8 inch thick and prepared with a single vee type groove. Plate *A* was welded by the multi-layer continuous method using a regular neutral flame. Plate *B* was welded by the multi-layer continuous method using a slight excess acetylene flame. Plate *C* was welded by the multi-layer step method using a slight excess acetylene flame. Plate *D* was welded by the multi-layer step method using a regular neutral flame. The same operator performed the welding of each of the plates and in each case the type of flame employed was carefully checked during the welding operation. The welds were then X-rayed and the exographs revealed welds entirely free from defects. Figure 1 shows the prints of each of these exographs.

Each plate was then cut up to provide a complete set of test specimens to comply with the A. S. M. E. Code requirements. All specimens were then stress relieved at 1200° F. for one hour and cooled in the furnace. After machining they were then tested to determine the physical qualities of the weld material. Table 1 gives the test data results on each set of specimen.

* Published in October 1936 issue of the WELDING JOURNAL.
† Research Director, Henry Vogt Machine Company.

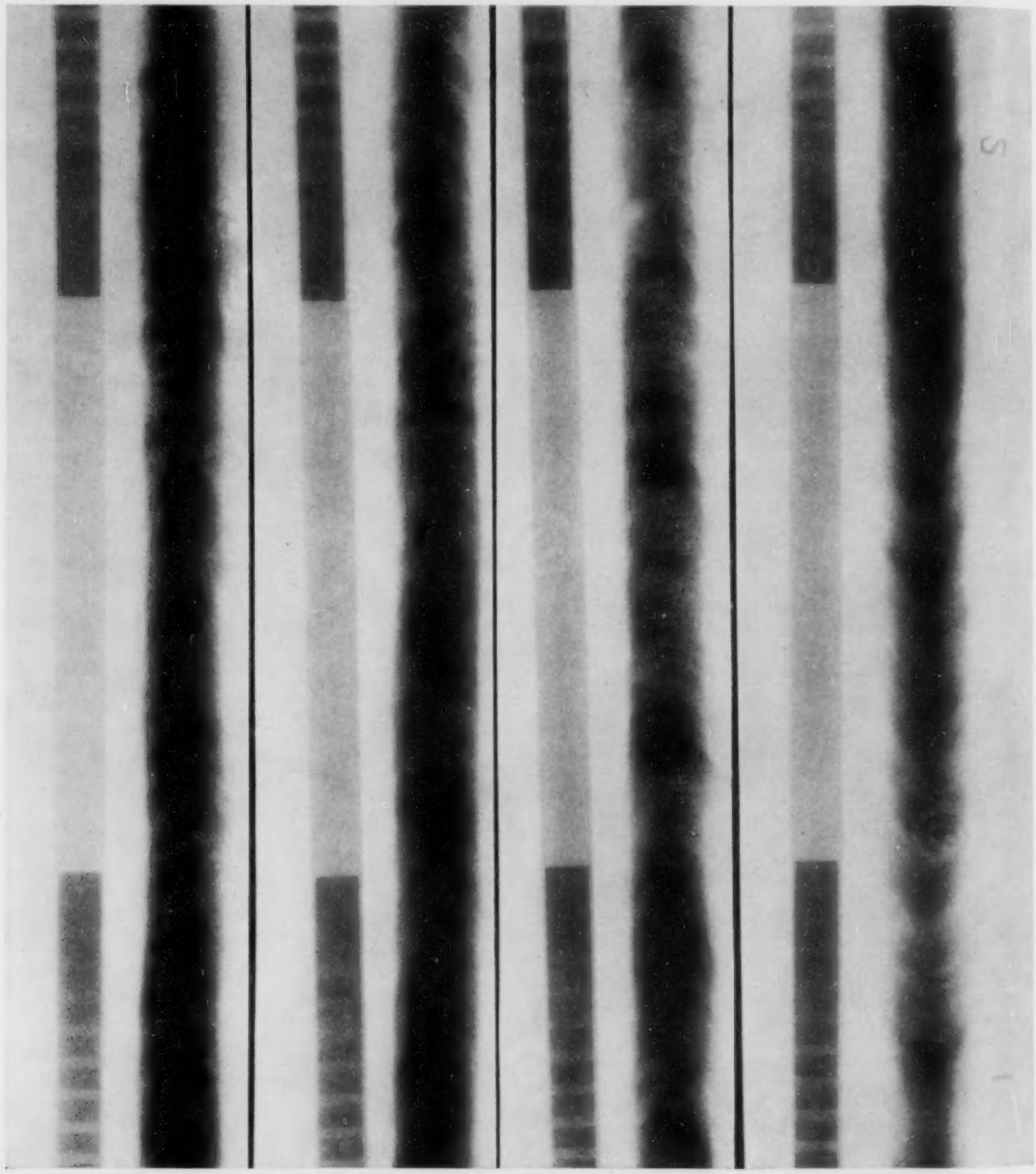

Plate A.—⅝ in. Thick. Multi-Layers —Continuous-Neutral Flame

Plate B.—⅝ in. Thick. Multi-Layers, Continuous—Slight Excess Acetylene Flame

Plate C.—⅝ in. Thick. Multi-Layer, Step Method—Slight Excess Acetylene Flame

Plate D.—⅝ in. Thick. Multi-Layer, Step Method —Neutral Flame

The results of the reduced section tension test, the bend test and the specific gravity test show that the requirements of the A. S. M. E. Code as set forth in paragraph U-68 of the Unfired Pressure Vessel Code and paragraph P-101 of the Power Boiler Code have been met. The requirements have also been complied with for the 0.505-inch diameter all-weld tension test as far as the tensile strength is concerned, but the elongation of the weld taken from plate *A* and *D* is not sufficient to satisfy the Code. The elongation of the welds taken from plates *B* and *C* are well above the requirements necessary to comply with the Code.

The physical qualities of the weld metal from plates *A* and *D*, which represent welding both by the continuous multi-layer method and the multi-layer step method, are considerably better than can be obtained by the single layer method. However, unless a special technique is employed in which the neutral flame is changed

Table I—Physical Test Data (Gas Weld)

Specimen Number	*A*	*B*	*C*	*D*
Reduced Section Tensile Test (Lb. per Sq. In.)	66,700	65,055	56,700	58,000
0.505-In. Diam. All-Weld Tensile Test (Lb. per Sq. In.)	62,550	64,120	63,650	64,500
Elongation in 2 In. (Per Cent)	16	28.5	25	17.5
Free-Bend Test (Elongation in Per Cent)	48.5	43.1	37.1	39
Specific Gravity	7.81	7.85	7.82	7.84

Specimens stress relieved at 1200° F. for 1 hr.

to slight excess acetylene flame, sufficient ductility is not obtained to pass the physical requirements for high-pressure vessel welding, in which the elongation of the 0.505-inch all-weld tension test specimen must be 20% or better. The elongation requirements of the specimens taken from the welds of plates *B* and *C* are considerably better than 20%, yet the welding method employed was identically the same as used in welding plates *A* and *D* except that instead of the neutral flame, a slight excess acetylene flame was used.

As outlined in Messrs. Rooke, Saacke and Kugler's article, there is little doubt but that the multi-layer method of oxyacetylene welding, either by the continuous or step process, produces physical characteristics in the weld metal which are superior to the welds made by the single layer method. In order to attain greater improvement in the physical qualities of the weld metal than that shown in Table 1, it is suggested that greater ductility can be obtained with no appreciable lowering of the tensile strength by changing the normally employed neutral flame to one having a slight excess acetylene flame which is carefully controlled to prevent fluctuation.

Actual cost per pound of deposited weld metal can be lowered by this method and welds can be consistently produced which are free from slag and porosity.

By A. S. DOUGLASS*

I FEEL somewhat unqualified to discuss this paper as it has to do with gas welding, whereas my experience has been almost entirely with electric arc welding. There are, however, some points on which I should like to comment. The principle point in this paper, namely, the grain refinement of earlier layers by the heat of successive layers of weld metal is a matter long understood and appreciated by those who have studied the electric arc fusion welding process. In a paper presented before the Society some years ago, reporting some experimental work done by The Detroit Edison Company, this principle was clearly recognized. It appears that the gas welders are just now arriving at a point to which the electric arc welders were forced long ago due to the difficulty of depositing a heavy bead in position welding by the electric arc method. In some of the best practice with arc welding, as many as eight or even more layers are used per weld in plate thicknesses of $^3/_4$ of an inch. It would be very interesting to see the work of this paper carried further with a view to determining whether grain refinement cannot be carried to a still higher degree of perfection by using a still greater number of layers. My feeling is that such is likely to be the case. I feel that in three layers the third and unrefined layer is too large a portion of the whole weld.

It is found in electric arc fusion welding that the larger number of small beads permits, by means of carefully cleaning the surface of each bead, the almost complete elimination of inclusions.

I have a feeling that the residual stresses in the finished weld would be less if the first bead were continued around the entire circumference of the pipe, prior to the laying of the second bead. The piling of the second bead on top of a sector only of the first bead, tends to build a section of great rigidity at one portion of the circumference. It seems to me that this would preclude anything like uniform distribution of the stress due to longitudinal contraction. I believe this is of great importance where stress-relieving is not carried out.

On the evidence found in this paper I should always prefer, on pipe to be used in severe service, as many as three layers, whereas the paper apparently contemplates only two layers in the lesser thickness under consideration. I should prefer the three layers due to the fact that the principle strength layer is doubtless the second one, and this layer with only two passes does not receive any refinement.

I wish to confirm one statement in the paper, namely, that test coupons can be flame cut by the use of a profiling flame cutting machine, and that the difference in result found between specimens so prepared and milled specimens is negligible. It is our intention to eliminate immediately the milling of test specimens in our own qualification work.

I find it difficult to criticize adversely this excellent paper which marks a decided step forward, but I feel that it is a little inclined to over-stress the matter of efficiency in welding. In the welding work which is giving us the greatest concern, namely, main steam piping for 650 pounds pressure, 850 degrees total temperature, we are taking every known precaution to obtain safe welds, surface cleaning by chipping of each bead, and careful stress-relieving. The outside cost of such a joint welded is $35.00. This competes with a joint which would otherwise have been selected which would have cost somewhere from $300.00 to $400.00 per joint. For services of this kind and in the interest of the welding industry, it seems essential that quality workmanship and a careful technique be given first consideration.

I completely agree with the final recommendation of the paper, namely, that multi-layer welding be used on all high-pressure, heavy wall pipe. I am sure that I should not wish to permit anything less than three layers, and I suspect that a careful investigation would lead me to require even more.

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* Construction Engineer, The Detroit Edison Company.

Some Pictures of Welding Applications

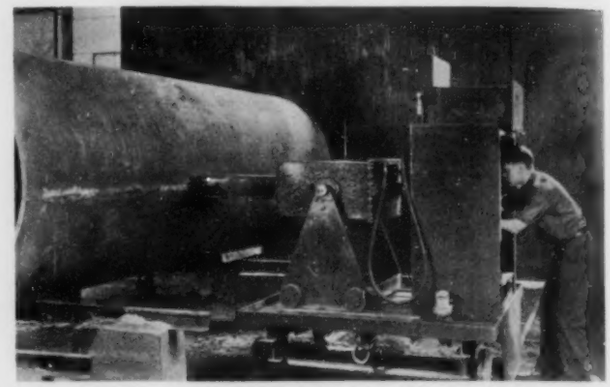
New High-Pressure Locomotive Boiler Is First of Its Type

By A. F. DAVIS*

WHAT is thought to be the first high-pressure boiler ever made with welded barrel and dome, under U-68 (Class I) rules of the A. S. M. E. Code for fusion welded vessels, was recently completed by Farrar and Trefts, Inc., Buffalo, New York.

The new boiler is of locomotive type and is for use in oil fields. The barrel, shown in the accompanying illustration, is 16 feet 6 inches long, $62^1/_2$ inches outside diameter and made of steel plate 1.15 inches thick, electrically welded with coated electrodes.

Welded construction of the barrel eliminated a large amount of caulking of seams which was necessary with the former method of construction employing riveting. The manufacturer reports that the seams remain permanently tight in the field thus assuring freedom from maintenance. The two logitudinal welds of the barrel were hammer tested at 575 lb. and leak tested at 700 lb. hydrostatic pressure, revealing high quality leak-proof seams. The welding was done with an electrode which provides weld metal having tensile strength of 65,000 to 75,000 lb. per sq. in.; ductility of 20 to 30 per cent elongation in two inches and density of 7.82 to 7.86 grams per c.c. Corrosion resistance of such welds is greater than mild rolled steel.



Barrel for High-Pressure Boiler, Claimed to Be First of Its Type Ever Built with Barrell and Dome Arc Welded to U-68 (Class I) A. S. M. E. Rules

* Vice-President, The Lincoln Electric Company.

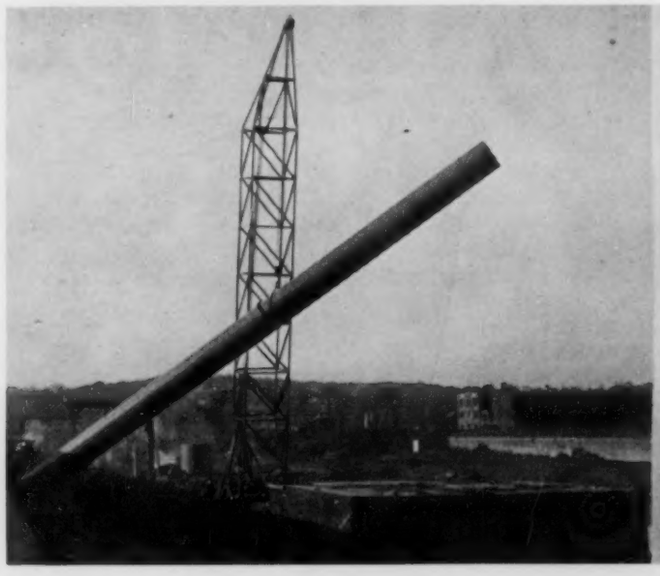
Welded Smoke Stacks

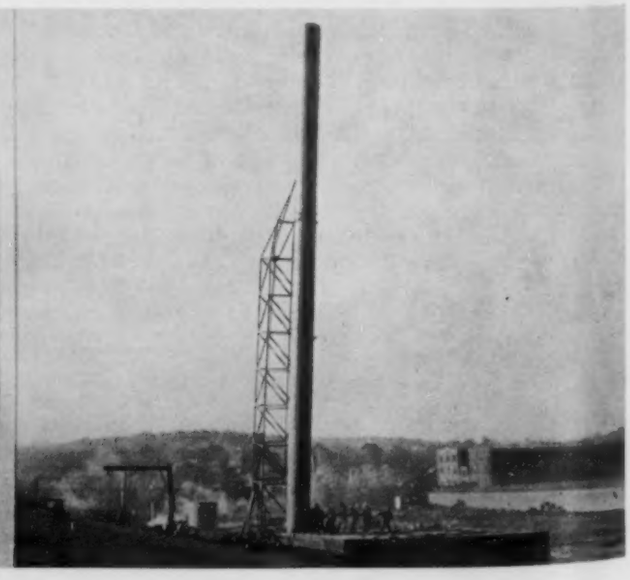
By GEORGE McNUTT**

BUILDING an all-welded steel heating plant to heat its 1200-foot factory at Peoria, Illinois, R. G. Le Tourneau, Inc., manufacturers of heavy grading equipment, where confronted with the problem of constructing and erecting a smoke stack tall enough to carry the smoke clear.

Inside the plant, one-quarter inch plate was prefabricated into an all-welded stack 104 feet tall, 57 inches in diameter and weighing approximately 10 ton. This is thought to be the tallest pre-fabricated steel stack ever erected. The stack is anchored to the floor and roof of the boiler house, which reduces its outside height to 83 feet. A portable tractor-powered Crane of all-welded design was built to lift and place this stack and for other heavy duty. This Crane rides on six 18 × 24 rubber tires. It is cable controlled from a Power Control Unit mounted on the tractor.

** Manager, Ads. & Sales Promotion Department, R. G. Le Tourneau, Inc.





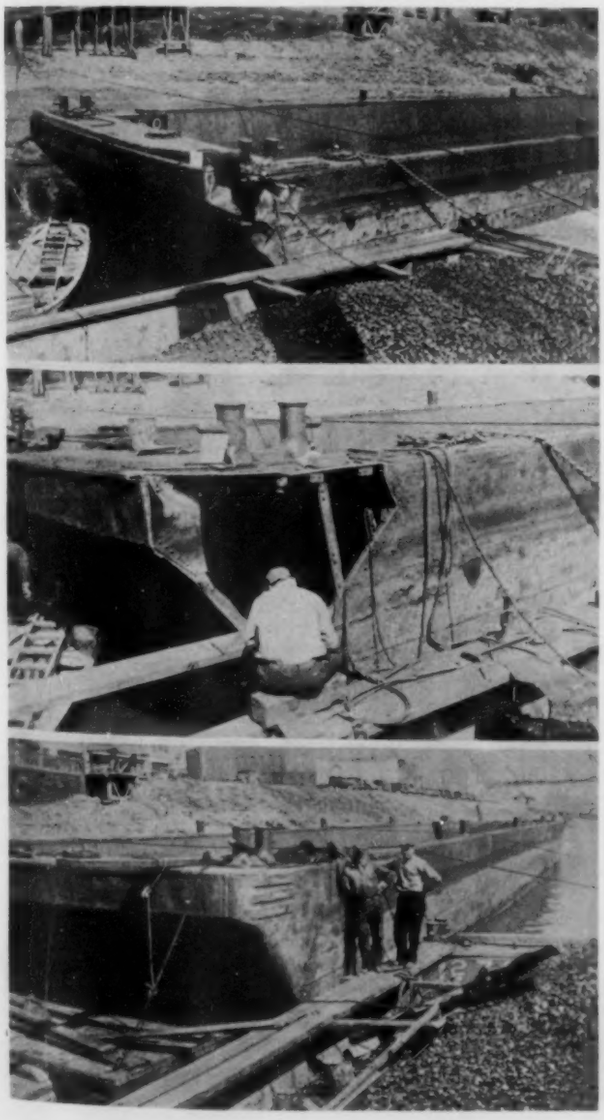
As used to erect this stack, a feat which it performed in 30 minutes, the Crane has an 84-foot boom. However, it is reversible, the boom becoming a tongue and the 22-foot tongue a boom, which gives it a 40-ton capacity for lifting an all-welded steel house now nearing completion in the Le Tourneau factory.

Welding Repairs Damaged Barges

By R. W. ORTH†

HOW the Pittsburgh Welding Company has repaired 181 damaged river barges with arc welding is indicated by the three accompanying illustrations, showing a barge with a damaged corner before, during and after the welding operations. According to E. H. Pacy, president of the company: "Of the 181 barges welded since 1933, not one has had a weld failure in spite of the severe punishment the repaired sections must undergo in service."

† News Bureau, General Electric Co., Schenectady, N. Y.



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WELDING SOCIETY ACTIVITIES
AND RELATED EVENTS

New Appointments

At the meeting of the Board of Directors held in Cleveland on Monday, October 19th, Mr. C. A. McCune was appointed Treasurer and Miss M. M. Kelly, Secretary for the administrative year 1936–1937.

Other appointments to standing committees will be made at a later date.

Inspection Trips at Cleveland

As indicated in the previous issue of the Journal the inspection trips arranged during the Annual Meeting of the AMERICAN WELDING SOCIETY in Cleveland on Friday, October 23rd, was a huge success. Everyone thought the trip was pleasant and instructive. The buses left the Hotel on schedule and arrived at the Wellman Engineering Plant; from there the party went to the Cleveland Crane and Engineering Co. plant and then to the Nela Park General Electric Offices and Laboratories. Here an excellent lunch was served by the General Electric Company. Following lunch the visitors were invited to see the "Kitchen Institute" and other novel and entertaining General Electric attractions at Nela Park.

Other social features including the stag party and the annual dinner were equally successful. At the dinner Dr. Wickenden of Case School of Applied Science gave an inspiring talk to those interested in welding.

Electric Arc Welding Machine Standards

(From News Release From NEMA)

The National Electrical Manufacturers Association announces the publication of the NEMA Electric Arc-Welding Machine Standards, Publication No. 36–37. This new publication is a reference work of practical information concerning the manufacture, test and performance of direct-current and alternating-current arc-welding machines; such as, motor generator sets, dynamotors, transformers and rectifier arc-welding units. Because these standards represent standardized practice in the United States, they will assist in harmonizing practices in the industry and promote production economies. They also clear up many troublesome problems for the buyer of arc-welding equipment and define numerous terms which have hitherto been subject to various interpretations.

Copies of the 20 page publication may be obtained from the National Electrical Manufacturers Association, 155 East 44th Street, New York City, at 50¢ per copy.

Protective Glasses

The National Electrical Manufacturers Association at a meeting in Cleveland on October 22nd voted to adopt as a step toward standardization, 2 × 4¼ in. as the standard size of all helmet and shield glasses for electric welding.

Bound Volume Journal

The AMERICAN WELDING SOCIETY has made arrangements for members who wish to have their Journals for 1936 bound in attractive, imitation black leather covers to do so by sending copies of the twelve issues to Russell-Rutter Company, Thirty-Third Street and Eighth Avenue, New York, N. Y., Att. Mr. Russell Lauben, Jr. A special reduced rate has been arranged at $1.75 per volume providing the issues of the Journal are sent to the binder on or before February 1st. The bill for the binding and return postage will be sent direct from the Society's office.

A Message from Our President

To the Members of the
AMERICAN WELDING SOCIETY:

Being catapulted, so to speak, into the midst of the AMERICAN WELDING SOCIETY'S activities, I have come to know the ramification of the Society's activities to an extent which would be impossible except for my official connection with the organization.

As a member of the Cleveland Section, although interested in our own local problems of membership and technical programs, I had little opportunity to know intimately the scope of the National Society's program, of the extent of the committee work on codes, welding symbols, nomenclature and welding procedure for machinery, bridges, pressure vessels and the score of other industrial weldments which need definite procedures to govern their welding.

I have just had the opportunity of seeing the result of several years work by the Subcommittee on Welding Symbols of the Nomenclature Committee. The almost endless task of getting industry to agree on one particular group of symbols, all embracing yet simple and clear, has finally been accomplished. This is just one of the really essential activities of your Society which has been done in a fine manner. When the work of this committee has been accepted by your Board of Directors, it will be published in the Journal and broadcast to the entire welding industry. It will prove one of the mile stones in the development of welding. The speed with which a standard such as this is accepted is dependent to a large extent on you. The more welding minded people who are members of the Society, the faster its acceptance by industry. The more rapidly this and other standards are adopted by welding fabricators, the higher the plane of welding, the better its products, the more successful the art of welding in industry.

All of the foregoing leads directly to your contribution to the art of welding through your efforts to build a bigger, a better, a more effective society. Through sheer force of numbers, we can expand our work in education, in legislation, in research, in establishing exact procedures and in giving you more knowledge on every conceivable phase of welding and gas cutting operations. I expect within this year to see our monthly Journal not only rejuvenated by splashing color onto the cover (which I probably should not have mentioned but let it surprise you by coming to you in its new dress) but that we will present more articles of wider interest to all of you. Circulation governs advertising, advertising governs Journal income. Expanded in-

come permits the publishing of more developments in research and industrial progress.

I think I said in last month's letter that this is your Society, your problem. Those at headquarters and on committee work who are giving unstintingly of time and effort and resources are going to carry on and build our Society into the type of organization we vision it in the future. Just how quickly these objectives can be achieved depends upon the rank and file of our membership. Think what double our membership will mean, what tripling it will mean, what quadrupling it will mean! This is entirely within the bounds of possibilities. I could name you ten men in Cleveland who brought in from five to eight new members each in ten days, and none of them—so I am told—used a club. They simply told the prospect what the AMERICAN WELDING SOCIETY had to offer. If each member would just try to get one new member, our membership would double in no time.

No technical society in America has a larger field of service with a more crying need for exact knowledge, no technical society has a greater opportunity for accomplishment which can be effective in the development of welded mechanical and structural equipment to out-service and out-perform that of any other known method of fabrication. The Society needs your help to do these things. I believe you will give it.

A. E. GIBSON, *President*
AMERICAN WELDING SOCIETY

Obituary

Frank P. McKibben

Frank P. McKibben, Consulting Engineer and Past-President of the AMERICAN WELDING SOCIETY, died on November 27th at his estate near Fayetteville, Pa. He was 65 years old. Professor McKibben was born in Fort Smith, Ark., and taught engineering more than twenty-two years at Massachusetts Institute of Technology, Lehigh University and Union College, Schenectady.

Surviving are his widow, Ariana Kennedy Elder McKibben; a son, by a previous marriage, Elliot S. McKibben, and a brother, Dr. William McKibben, and a sister, Mrs. J. Raymond Williams, both of Miami, Fla.

Professor McKibben was President of the AMERICAN WELDING SOCIETY for two years 1932–1934.

Frank P. McKibben, was a bridge engineer of international reputation. He acted as designing engineer and engineer of construction on a drawbridge of the City of New Bedford; as designing engineer of the elevated railway structure and buildings of the Boston Elevated Railway Company. At one time he was connected with the Berlin Iron Bridge Company and the Edge Moor Bridge Company, which was later absorbed by the American Bridge Company. As Assistant Bridge Engineer for the Massachusetts Railroad Commission he made calculations for and examined 1500 railroad bridges and 800 highway bridges during a period of six years. Prof. McKibben for ten years had

Frank P. McKibben

in charge the operation of the Fritz Testing Laboratory which he designed and equipped. He acted as consulting engineer to the Attorney-General's Office of Pennsylvania in the investigation of the Austin, Pa., dam. He was also consulting engineer for the Pennsylvania Water Supply Commission in 1914.

He designed the following structures: Connecticut River Bridge at Chicopee, Mass.; Merrimac River Bridge at Haverhill, Mass.; Bridge at Gloucester, Mass.; Bridge at Beverly, Mass.; Twenty-three Bridges in Western Massachusetts; Bridge in Central Park, Schenectady, N. Y.; New Bedford, Mass., drawbridge with revolving weight of 2,000,000 lb.; steel work for New Bedford Saving Bank.

He was engineer in charge of design and construction of Venango County Bridge, Oil City, Pa.; Smith Street Bridge, Rochester, N. Y., Ridge Road Bridge (Veterans' Memorial), Rochester, N. Y.

Welding

In 1922, with Ernest Humphrys, made the first tests on fillet welds in longitudinal shear.

During the period 1927 to the time of his death, he designed a large number of important all-welded and partially welded buildings.

During this period he addressed over 100 audiences (total attendance 20,000) on the subject of structural steel welding, and has written 71 articles pertaining to welding.

He has also acted as City Engineer for the City of Schenectady for two years and had charge of the design and construction of sewers, streets, boulevards, costing several million dollars. He has acted as consulting engineer for more than thirty different companies.

Publications

"Steel Bridge Construction" in American Civil Engineers Handbook; "Concrete Arch Bridges" in Concrete—Plain and Reinforced; about 160 technical articles (other than those pertaining to welding) in scientific and technical journals and in publications of engineering societies; seventy-one articles relating to welding.

Welding Society Affiliations

Professor McKibben was well known to the Welding Society, having served in addition to President as Senior Vice-President for two years, member of the Board of Directors and Executive Committee, Structural Steel Welding Committee, Structural Steel Welding Steering Committee, Committee on Building Codes and Committee on Pipe Welding. He was awarded the 1931 Samuel Wylie Miller Medal for his outstanding work in the development of the art of Structural Fusion Welding.

Welding Handbook

At the meeting of the Board of Directors on October 19th it was voted to proceed with the preparation of a Handbook for the AMERICAN WELDING SOCIETY. The Editorial Committee has prepared a tentative list of chapters and invites the cooperation of every one in making suggestions for revisions or additions. For those chapters where authors are not shown, the Editorial Committee has not yet received the acceptance from the suggested authors of their assignment. Suggestions for revisions and additions should be in the hands of the AMERICAN WELDING SOCIETY not later than January 1st. A time limit has been set of February 15th for the receipt of chapters from the various authors.

Following the list of chapters there is reproduced copy of the instructions which went out to each author.

AMERICAN WELDING SOCIETY
Proposed List of Authors
WELDING HANDBOOK

PREFACE

Economics of Welding

PROCESSES

Chart of Processes with Explanatory Text
Technical Fundamentals:
- Arc Welding—C. A. Adams, Consulting Engineer
- Gas Welding—
- Thermit Welding—
- Resistance Welding:
  - General—R. L. Briggs, Thomson Gibb Electric Welding Company
  - Spot—H. A. Woofter, Federal Machine & Welder Company
  - Wheels, Points and Clamps—J. A. Weiger, P. R. Mallory & Co.
  - Controls—C. Stansbury, Cutler Hammer Co. (In cooperation with General Electric Co. & Westinghouse E. & M. Co.)
  - Tensile and Shear Strengths—
- Metallurgy of Welds—J. C. Hodge, Babcock & Wilcox Company
- Alternating Current Arc Welding—C. J. Holslag, Electric Arc Cutting & Welding Company

Collateral Processes:
- Oxyacetylene Cutting—J. J. Crowe, Air Reduction Sales Company
- With Other Fuel Gases—E. M. Evleth, Bastian Blessing Co.
- Arc Cutting—C. J. Holslag, Electric Arc Cutting & Welding Co.

Stress-Relieving—S. C. Hollister, Cornell University
Soldering (Soft and Silver)—R. H. Leach, Handy & Harman and Geo. O. Hiers, National Lead Co.
Surfacing (Hard and Tough)—(Chester Mott, Stoody Co. confer with Haynes Stellite).
Sprayed Metal Coatings—E. V. David, Air Reduction Sales Co.
Special Processes:
Atomic Hydrogen—J. T. Catlett, General Electric Company
Shielded Arc—S. C. Osborne, Wilson Welder and Metals Co.
Automatic Processes:
Metal Arc Welding—C. H. Jennings, Westinghouse Elec. & Mfg. Co.
Gas Welding—J. L. Anderson, Air Reduction Sales Co.
Carbon Arc Welding—A. F. Davis, Lincoln Electric Co.
Resistance Welding—R. T. Gillette, General Electric Co.
Accessories:
Jigs and Fixtures—
For Resistance Welding — H. C. Cogan, National Electric Welding Machine Co.
Protective Appliances — Thomas A. Willson, Vice-Pres., Willson Products, Inc.

MATERIALS AND TESTING

Base Metal—Ferrous:
Carbon Steel—F. N. Speller,* National Tube Company & N. L. Mochel, Westinghouse Elec. & Mfg. Co.
Cast Iron with Bronze—
High Manganese Steels—John Howe Hall, Taylor-Wharton Iron & Steel Co.
Alloy Steels:
Chromium Irons and Steels—E. C. Chapman and A. J. Moses, Hodges-Walsh, Weidner Company
Austenitic Chrome Nickel Steels—P. F. McEvoy, Struthers Wells Co.
Low Alloy Steels—Practical—A. E. Gibson, Wellman Engineering Co.
—Metallurgical — J. C. Hodges, Babcock & Wilcox Co.
Base Metal—Non Ferrous:
Copper and Its Alloys—I. T. Hook, American Brass Company
Aluminum and Its Alloys—G. O. Hoglund, Aluminum Company of America
Nickel and Its Alloys—J. G. Schoener and F. G. Flocke, International Nickel Company
Filler Metal:
Standard Specifications—C. A. McCune, Magnaflux Corporation
Covered Electrodes—J. H. Deppeler, Metal & Thermit Corporation
Qualification of Operators—J. W. Owens, Fairbanks-Morse Company
Qualification of Processes—W. D. Halsey, Hartford Steam Boiler Insp. & Ins. Co.
Testing:
Non-Destructive Tests—Magnetic and Sonic
—Radiography — H. H. Lester, Watertown Arsenal
Fatigue Tests—H. F. Moore, University of Illinois
Inspection of Pressure Vessels—E. R. Fish, Hartford Steam Boiler Insp. & Ins. Co.
Welding Codes—

APPLICATIONS

Marine Construction:
Ships—G. H. Moore, Jr., Newport News Shipbuilding & Dry Dock Co.
Barges—C. W. Bryan, Jr., Federal Shipbuilding & Dry Dock Co.
Pressure Vessels:
Gas Welding—
Progressive Welding—Victor Mauck, John Wood Manufacturing Co.
Petroleum Vessels—T. McLean Jasper, A. O. Smith Corporation
Boilers—
Thin Wall Vessels—R. E. Cecil, W. B. Scaife & Sons Company
Evaluating Existing Vessels—W. Samans, Atlantic Refining Company
Vessels for Low Temperatures—R. K. Hopkins, The M. W. Kellogg Company
Storage Tanks:
Field Welding—E. H. Ewertz, Consulting Engineer
Piping and Fittings:
Gas Welding—A. W. Moulder, Grinnell Company
Arc Welding—D. H. Corey, Detroit Edison Company
Resistance Welding (Longitudinal Joints)—W. M. Neckerman, Republic Steel Company
Pipe Lines of Large Diameter:
Arc Welding—H. C. Price, H. C. Price & Company
Gas Welding—
Structural Steelwork:
Buildings—Gilbert D. Fish, Consulting Engineer
Bridges—P. G. Lang, Jr., Baltimore & Ohio Railroad Co.
Welding Fabrication—E. T. Blix, Mississippi Valley Structural Steel Co.
Street Railway Track—E. M. T. Ryder, Third Avenue Railway System
Machinery:
General—Everett Chapman, Lukenweld, Inc.
Locomotive Construction—J. Partington, American Locomotive Company
Steel Mill Equipment—C. A. Wills, Wm. B. Pollock Company
Automotive Products—C. A. Bowlus, Welding Accessories Company
Aircraft—J. B. Johnson, Material Branch, Air Corps, War Department
Railroad Rolling Stock:
Standard—J. W. Sheffer, American Car & Foundry Company
Light Weight—
Under Water Gas Cutting—C. Kandel, Craftsweld Equipment Company
Repair and Maintenance—A. F. Keogh, Sound Welding Company
Maintenance of Way Welding:
Arc—
Gas—
Thermit—

EDITOR'S NOTE:
Several additional chapters will be added by the Editorial Committee.

CIRCULAR OF INFORMATION for AUTHORS of THE WELDING HANDBOOK of the AMERICAN WELDING SOCIETY

GENERALITIES. The Society has directed the Editorial Committee to proceed with the preparation of the handbook and the work is now under way.

It is thought that a statement of policy will be helpful in guiding the individual authors in the preparation of their chapters.

Authors are requested to look over the complete list of chapters, of which a revised copy is given above, in order that they may obtain an idea of the material to be covered in their respective chapters.

The Editorial Committee will eliminate any important gaps or over-lapping and will insure continuity of style. All chapters will be submitted to five or six people or concerns particularly interested in the subject in addition to the Editorial Committee, and most chapters will be submitted to, say, ten or fifteen parties interested. If five copies of the manuscript can be sent to the Committee it will facilitate the work.

It is proposed to include in the handbook all the technical information that a welding engineer, supervisor or inspector in general practice is likely to desire, presented in the most concise form possible by specialists whose experience will permit them to write authoritatively. General descriptive matter and general information are to be reduced to a minimum. It is assumed the book will be used by those in search of specific information. In general, no reasoning or hypotheses are to be included and there is to be no derivation of formulas. A handbook should give results only.

AUTHORITATIVE TREATMENT. Contributors to this book should exercise critical judgment on the data which they present. For example, the contributor should sum up the results of experience and experiment, and should give a statement of the best values or practice to use under given conditions, rather than to tabulate the results of a number of tests and leave the reader to select from them.

CONTRIBUTORS AFFILIATED WITH SPECIAL COMPANIES. Many of the contributors to this handbook are necessarily men affiliated with special companies, since they alone have the detailed knowledge of their subjects which is desired. It would not be possible to prepare this handbook without the help of those specialists. It is particularly desirable that such contributors should present the facts of general practice, in such a manner as not to infer that they treat chiefly of the practice of their own Company.

HEADINGS AND IMPORTANT WORDS. The headings for main divisions of chapters will be centered. Each paragraph should begin with a side heading, giving the topic under discussion, printed in bold-face type. The subparagraphs will not, in general, have headings, but may be treated in the same way as the paragraphs in cases where the heading for a paragraph is not sufficiently in-

clusive to indicate the contents of its subparagraphs, or in cases where there are many subparagraphs following one paragraph.

TABLES. As far as possible, information should be condensed in tables and charts rather than take the form of descriptive matter.

ILLUSTRATIONS. Nearly all of the figures in this book will be line drawings. The general use of photographs is not desired. It is suggested that in the drawings all lettering be over-size with thin lines and open space in the center. Reduction of line sketches always brings about a relative thickening of lettering. The available area on a page will be 3 inches wide by 5⅝ inches high, inside of border. Illustrations and Tables should be of such proportions as will permit their legible reproduction within this area. The captions will be type-set, and sufficient space therefore should be allowed in proportioning the illustrations. When an illustration is being lettered, the size of lettering should suit the contemplated reduction. Lettering should preferably run parallel to the width of the page, wherever this is feasible. If it has to be parallel to the height of a page it should run from bottom to top of page, so as to be read from right-hand side.

BIBLIOGRAPHY AND REFERENCES. Each chapter may, if desired, end with a short bibliography of the most important works dealing with the subject.

RELATION BETWEEN THE CHAPTERS OF THE HANDBOOK. The authors of chapters dealing with engineering practice in a given field may assume that the fundamentals will be treated in other chapters. However, in case of doubt, authors are urged to include any desired statement in such form as will permit the Editorial Committee to delete overlapping portions.

PREPARATION OF MANUSCRIPT. The manuscript should be typewritten and five copies furnished when practicable. The chapter is the unit in this book. Each table and drawing should be on a separate sheet. Side headings, and important words or phrases which are to be put in capitals, should be underlined.

LENGTH OF CHAPTERS. The length of chapters will vary. The average length should be about 5000 words.

Each author is requested to send in as early as possible, 5 copies of a skeleton outline of his chapter in order that unnecessary duplication may be avoided.

Authors are requested to prepare and transmit their chapters to Society headquarters not later than February 15, 1937. Each author will be given opportunity to review galley proof of his chapter as finally edited.

SECTION ACTIVITIES

BOSTON

On November 19th, the members were privileged to meet at the River Works, Lynn, of the General Electric Company. The program, offered by the General Electric Company consisted of a skit on the subject of the proper choice of welding procedures to use for specific production problems. Those taking part in the skit were Messrs. J. E.Waugh, Roger Clark, R. T. Gillette and Walter Reed, all of the General Electric. Over 500 welded samples were on display after the meeting.

The December meeting will be a joint meeting with the American Society of Mechanical Engineers, Boston Section, and the Plant Engineers Club, and will be held at the Watertown Arsenal, Watertown, Mass., on December 17th. Starting at 2 P. M., the members will visit the various shops at the Arsenal; at 6 P. M., dinner will be served at $1.00 per person, and the evening session is scheduled to start at 7:30 P. M. Two papers will be presented at the evening session. Lt. Col. J. Kirk will speak on "Machining Gun Tubes"; and Mr. W. L. Warner will talk about "Welding of Low Alloy High Tensile Steels."

CHICAGO

An interesting meeting on the subject "Maintenance Welding" was held by the Chicago Section on Friday, November 20th at Mission Hall, Armour Institute of Technology. The speakers were Fred Lasker, of the Lasker Boiler & Engineering Corp.; Tom Jones, of the South Works, Carnegie-Illinois Steel Co. and E. D. Benton, of the Elkhorn Coal Company. Maintenance by welding, of boilers, industrial equipment and power equipment was covered, and lively discussion followed. A special feature of the evening, which preceded the speakers, was M. K. Hudson, of the U. S. Coast Guard, who showed a highly interesting motion picture entitled, "Performance of the Coast Guard."

CLEVELAND

The December meeting of the Cleveland Section will be held on the 11th at which time Professor Fred L. Plummer will give a talk on "Model Aids in Welding Design." This meeting will also feature a talk by Mr. Fred Folberth who will talk on "The Airship Hindenberg," which will be given before the regular speaker.

DETROIT

The monthly meeting of the Detroit Section was held on December 4th at the Fort Shelby Hotel. Mr. A. E. Gibson, Executive Vice-President of The Wellman Engineering Company and the President of the Society, spoke very interestingly on "Low Alloy Steels in Welding." The talk was illustrated by slides.

PHILADELPHIA

There was a fine turnout at the November 16th meeting of the Philadelphia Section and both speakers gave splendid talks. Mr. R. K. Hopkins, Director, Metallurgical Research, The M. W. Kellogg Co, discusses "Welding in Chemical and Refining Equipment" and Mr. Walter Samans, Chief Engineer, Atlantic Refining Co. supplemented this talk with a discussion covering the experience of the refining industry in service of plain carbon steel, spray coated steel and lined vessels.

The members of the Philadelphia Section received a special invitation to attend the meeting of the Association of Iron and Steel Engineers, Philadelphia Section, which was held on Saturday, December 5th at the Engineers Club. Mr. Wm. E. Crawford, Engineer in Charge of Welding Activities of the A. O. Smith Corporation, addressed the meeting on "Fitting the Weld to the Job."

PITTSBURGH

The regular meeting of the Pittsburgh Section was held in the East Room of the Roosevelt Hotel Wednesday Night, November 18th, at which time Mr. L. C. Bibber, welding engineer of the Carnegie Illinois Steel Corporation gave a most interesting talk on welding "Symbols."

As Chairman of the AMERICAN WELDING SOCIETY Subcommittee to correlate and revise symbols, Mr. Bibber was in a position to present a preview of the work done by his committee on this important work.

By means of illustrating slides and a black board, Mr. Bibber gave an exceedingly clear description of the symbols the AMERICAN WELDING SOCIETY will undoubtedly accept as the standard for welding specifications.

Over fifty members and guests were present, and among them were many engineers, draftsmen and others, whose interest in this particular phase of welding will become of paramount importance in the future.

Following the talk, many questions were asked and an interesting discussion followed.

The next meeting of the Pittsburgh section will be held in January, at which time it is planned to have a joint meeting with one of the other local Engineering Societies interested in Welding.

SAN FRANCISCO

The San Francisco Section held a meeting on Friday, November 20th at the Athens Athletic Club, Oakland. Mr. K. V. King again gave a résumé of the outstanding articles pertaining to the welding process appearing in the AMERICAN WELDING SOCIETY JOURNAL, and other contemporary literature. The principal speaker was Prof. N. F. Ward, whose topic was "Review of Recent Developments in Low Alloy Steel Welding."

1936 Book of A. S. T. M. Standards

The Book of A. S. T. M. Standards, which is published every three years, contains all of the standard specifications, methods of testing, definitions, and recommended practices adopted by the Society. The current volume is issued in two parts—Part I (910 pages) includes all standards relating to metals; Part II (1480 pages), those covering non-metallic materials.

Of the 181 standards in Part I, 109 cover ferrous metals, while 60 relate to non-ferrous metals, and 12 involve metallography and general testing methods. Price $7.50

This book may be obtained from the American Society for Testing Materials, 260 S. Broad St., Philadelphia, Pa.

THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

Sponsored by American Welding Society and American Institute of Electrical Engineers

Welding Research Committee of Engineering Foundation Secures Cooperation from Industry

The Welding Research Committee, launched by Engineering Foundation with an appropriation of $7000 about a year ago, has secured pledges of support from leaders of industry. In order to provide an opportunity for the Committee to state its case, Engineering Foundation arranged a luncheon conference at the Engineers' Club, New York, on Friday, May 29th. Some twenty key executives representing various phases of industry were invited to attend. The proposed project of a coordinated comprehensive program of research in the welding field was well received. An outline of the organization and some of the activities to date were presented and is published elsewhere in this bulletin.

Mr. G. L. Knight, Vice-President, Brooklyn Edison Company, a member of the Foundation Board, representing chairman Charlesworth, presided.

Professor C. A. Adams, of Harvard University, Chairman of the Committee, briefly outlined the growing importance of welding touching as it does on every phase of industry that uses metals in some form or another. Professor Adams indicated that welding research on the part of companies, individuals, universities, and on a cooperative basis, had made possible the rapid growth and advancement of the welding industry. He also indicated the advantages to be derived through cooperation in these several matters.

Mr. Critchett, Colonel Jenks and W. Spraragen, each in turn briefly indicated the plans for making available the knowledge in literature here and abroad published in hundreds of journals and many languages; the collection and analysis of the results of research work in various industrial companies; the gearing in of the work of the Committee to meet the needs and desires of industry; and the benefit derived from some sixty investigations now under way in leading universities of the United States and Canada.

Executives present pledged support and cooperation from their companies, and indicated that they would contribute for the first year sums ranging from $400 to $1500. Most of the companies indicated that future support would be forthcoming as the Committee demonstrated its ability to render service.

Mr. Herman Van Fleet, Vice-President, Air Reduction Company, endorsed the project and offered the cooperation of his company, and particularly their research laboratory. Mr. Isaac Harter, Vice-President, Babcock and Wilcox Company, pointed out that welding is one of the most widely used tools in industry. He also pointed out that the answers to many of the questions were not known, and stressed the need for research work.

Mr. J. Winlock, Chief Metallurgist, representing Mr. E. G. Budd, President, E. G. Budd Manufacturing Company, pointed out that his company used all types of welding, although they were particularly interested in the various forms of resistance welding. He suggested that the Committee make available a series of progress reports.

Mr. H. C. Boardman, Vice-President, Chicago Bridge and Iron Works, indicated that there was particular need for basic knowledge on stress relief in thick-wall vessels, and pledged the continued support of his company to the work.

Mr. A. C. Weigel, Vice-President, Combustion Engineering Company, cautioned the Committee in its digest of literature, to eliminate the great quantity of misleading information.

Mr. W. L. Merrill, Industrial Engineering Department, General Electric Company, stated that in good times, 1929, the company had employed some 250 welders, and now with a total output of about one-half of that existing at that time, they were employing 550 welders. This indicated the relatively growing importance of welding as a manufacturing tool. On refrigerators alone, seventy-two miles of seam welding are made in a single day during maximum production.

Mr. A. J. Wadhams, Vice-President, International Nickel Company, stated that the importance of welding to his company was from the point of view of the use of the products of his company in industry. He suggested that the Committee make periodical reports of progress and very brief summary statements prepared for the executives.

Mr. S. Nicholson, Vice-President, Westinghouse Electric and Manufacturing Company, confirmed the importance of welding to his company and its desire to cooperate.

Mr. G. L. Knight stated that Mr. R. H. Tapscott, Vice-President, New York Edison Company, had authorized him to pledge financial support to the work of the Committee, and indicated that the public utilities had a keen interest in welding, both from the use of welding in their own plants and as a power load.

Mr. J. H. Critchett, Vice-President, Union Carbide and Carbon Research Laboratories, stated that his company enthusiastically endorsed the project, and will cooperate in every way possible.

Similar pledges were made by Mr. F. T. Llewellyn, representing Mr. R. E. Zimmerman, Vice-President, United States Steel Corporation; Mr. Quincy Bent, Vice-President, Bethlehem Steel Corporation; and Mr. A. E. Gibson, Vice-President, Wellman Engineering Company. Mr. J. H. Davis, Chief Engineer of Electric Traction of the Baltimore & Ohio Railroad, representing Mr. Daniel Willard, President, stated that the railroads were potentially one of the largest users of welding, and that the Committee ought carefully to prepare its case for presentation to the railroads as a group probably through the Association of American Railroads.

A number of suggestions were made of other industries which should be approached, including oil, pressure vessels, automotive and ship-building. Some eight to ten thousand dollars were pledged by the representatives present, or by letter. The Committee seeks to supplement the contribution of $5000 for the next year to be received from The Engineering Foundation, with twenty to twenty-five thousand dollars from industry.

The Engineering Foundation Welding Research Committee

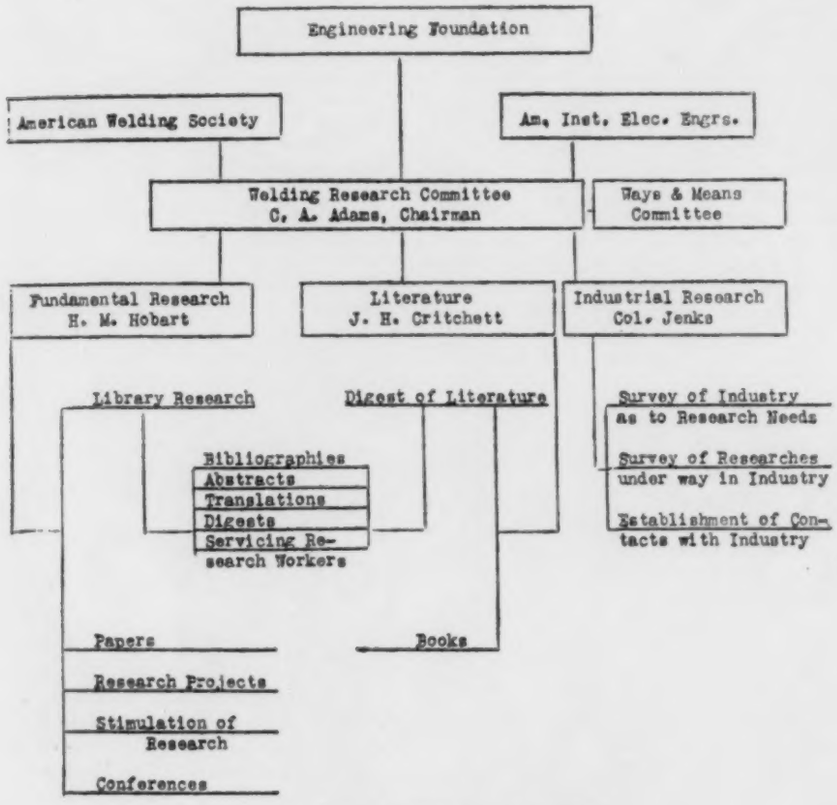
Progress Report for Period Ended April 15, 1936

Organization

At the invitation of the American Institute of Electrical Engineers a conference of interested representatives of governmental departments, universities and companies was held on April 22, 1935. This conference transmitted to The Engineering Foundation suggestions for the appointment of a suitable Research Committee to formulate and administer a comprehensive, coordinated program of welding research to be sponsored jointly by the American Institute of Electrical Engineers and the AMERICAN WELDING SOCIETY.

A Welding Research Committee has been appointed consisting of the following individuals:

C. A. Adams, *Chairman*, Pierce Hall, Harvard University, Cambridge, Massachusetts
J. H. Critchett, Vice-President, Union Carbide and Carbon Research Laboratory, 30 East 42nd Street, New York
J. J. Crowe, Engineer-in-charge of Apparatus Research and Development Department, Air Reduction Sales Company, 100 Forrest Street, Jersey City, N. J.
C. L. Eksergian, Chief Engineer, Budd Wheel Company, 12141 Charlevoix Ave., Detroit, Michigan
H. M. Hobart, Consulting Engineer, General Electric Company, Schenectady, New York



Organization Chart Welding Research Committee

D. S. Jacobus, Advisory Engineer, The Babcock and Wilcox Company, 85 Liberty Street, New York
G. F. Jenks, Commanding Officer, Watertown Arsenal, Watertown, Massachusetts
F. T. Llewellyn, Research Engineer, United States Steel Corporation, 71 Broadway, New York
W. Spraragen, *Secretary*, Consulting Engineer, 29 West 39th Street, New York

The project has been officially approved by the American Institute of Electrical Engineers and by the AMERICAN WELDING SOCIETY.

Financial Support

The Foundation made possible the launching of this project with grants totaling $7000 for the period ending September 30, 1936. Request for $5000 is now being made to the Foundation and to industry for $15,000.

Appointment of Subcommittees

The work has been divided among three subcommittees:

(*a*) Literature—J. H. Critchett, *Chairman*
(*b*) Fundamental Research—H. M. Hobart, *Chairman*
(*c*) Industrial Research—G. F. Jenks, *Chairman*

Review of Literature

One of the first steps is a comprehensive critical summary of research results and experience as reported in the technical literature of the world. Monographs are to be prepared which will provide a reliable foundation for further research, and supply to welding metallurgists, engineers and foremen the essential information now scattered through several thousand journals and text-books in many languages.

A card bibliography has been assembled which now totals about 15,000 references. A classification system has been prepared. Abstracts have been made of the important available literature published in French, Italian and Spanish. Critical digests have been made of a few selected subjects. Further divisions of the work will be made and assigned to experts. A competent editor will be employed.

Fundamental Research

This subcommittee had the advantage of several years' progress in interesting 60 important universities in fundamental research problems. Progress has been made in interesting additional universities. During the Summer of 1936 the committee expects to compile a list of fundamental research problems needing investigation, to be amplified by selected bibliographical references.

A system for making translations of important foreign articles has been established. At least a dozen important articles have been translated and made generally available. This represents a contribution in kind amounting to about $1000.

A successful conference of interested university workers was held in Chicago in October 1935 at the time of the fall meeting of the AMERICAN WELDING SOCIETY and the Metal Congress Exposition. Another conference is being planned for October 1936 at Cleveland.

Funds are needed to provide an assistant to the committee and to permit small grants-in-aid to specific investigators for the purchase of materials, apparatus and some services where these grants will materially expedite progress.

Industrial Research

A subcommittee is being organized under the chairmanship of Colonel G. F. Jenks, to survey industrial research activities in welding and to provide an organization to correlate these activities to the advantage of the welding industry.

The immediate problem is to ascertain what welding researches, not of a confidential nature, are under way, contemplated or needed by industry. The data thus obtained will be made available to sub-subcommittees now being organized to study the possibilities of correlation of activities.

The following seven Material Sub-subcommittees are being organized at this time:

Cast Iron—(*Chairman* not yet named)
Carbon Steels—J. C. Hodge, *Chairman*
Low-Alloy Steels—J. H. Critchett, *Chairman*
High-Alloy Steels—(*Chairman* not yet named)
Aluminum Alloys—G. O. Hoglund, *Chairman*
Copper Alloys—(*Chairman* not yet named)
Nickel Alloys—O. B. J. Fraser, *Chairman*

Three Functional Sub-subcommittees are being organized:

Methods of Testing—M. F. Sayre, *Chairman*
Analysis of Weld Failures—W. D. Halsey, *Chairman*
Weld Stresses—Causes and Effects—E. Chapman, *Chairman*

This committee held a meeting on February 17, 1936, and intends to hold another in the Summer, at the Watertown Arsenal.

Money will be needed to correlate results obtained and to make them available to industry.

Office

A small office has been established in Engineering Societies Building, New York.

C. A. ADAMS, *Chairman*

Progress in Welding during the Second Half of 1935*

By W. LOHMANN AND W. SCHNEIDER

1. Effect of Materials

The weldability of alloy steels with special reference to hardness phenomena in the transition zone is treated by F. Rapatz.[1] His experiments comprised gas welding as well as arc welding with coated, austenitic and cored electrodes, with plain carbon steels of different carbon contents, chromium-molybdenum, chromium-vanadium and chromium-nickel steels as plate materials. The principal difficulties in welding steels with the higher carbon contents lie in hardness phenomena as well as in poor penetration and blow-holes. The hardness in the transition zone is to a great extent affected by the heat developed in welding. As previously shown, plain carbon steel is relatively easy to weld by gas because the hardness increase in the broad, heat-affected zone is small. With arc welding, on the other hand, there is generally an abrupt increase in hardness in the immediate vicinity of the weld, which very rapidly drops to that of the parent metal as the distance from the weld is increased. This hard zone is explained by the rapid flow of heat to parent metal. The increase in hardness is more pronounced the higher the content of carbon or hardening alloying element.

According to Rapatz the cored electrode is superior to the heavy coated electrode, while the austenitic electrode is about the same as the latter in plain carbon steel. The same is true also when the parent metal is a Cr-V, Cr-Mo or Cr-Ni steel. Rapatz points out that the undesirable increase in hardness in the transition zone can be avoided in steel St 52 by using the correct alloying elements. The cored electrode is not only less expensive than coated and austenitic electrodes, but it has sufficient viscosity to be deposited without trouble in any position. The chief application for austenitic electrodes is in alloy steels, the weld being extraordinarily ductile even in steels that tend to harden. As earlier work showed, the nickel alloy steels are best in this respect.

Rapatz shows that the usual austenitic manganese steel electrode is not proper for welding Hadfield manganese steel because, on account of martensite formation, the transition zone is very brittle and shrinkage cracks are formed. For this kind of welding he recommends a manganese alloy electrode with carbon as low as possible.

V. Napravnik and St. Popov[2] compared hand- and electric-welded chains made of wrought iron and soft steel. It was first found that, by placing the weld in the most favorable position, the hand-forged chain gave 50% higher elongation than the electric butt-welded chain. There is no difficulty with either material in hand welding, which gives extraordinarily uniform strength in every link. In resistance welding the wrought iron is not so good as soft steel. This is related to the high slag content of the former which gives rise to poor union. The authors conclude from all their experiments that wrought iron is preferable for hand-welded links since it is better suited for forge welding. On the other hand, wrought iron is quite unsuitable for resistance welded chain; soft steel is always to be preferred in this case.

The following questions should be borne in mind, according to W. H. Hatfield[3] in the choice of filler rods for special steels: must the weld have simply physical properties the same as or similar to the parent metal, or must the chemical composition be the same? The first case usually includes structural steels; the second includes corrosion-, acid- and heat-resisting steels. If both conditions must be fulfilled, difficulties are encountered which are generally attributable to the hardening tendencies of the special alloy steels. Considerable confusion also exists as to the applicability of the different welding processes to the welding of alloy steels. The usual welding processes are applicable for plain carbon steels up to 0.8% C, according to Hatfield. For arc welding this does not correspond to the reviewers' experience because plate thickness plays a large part in determining the best welding method for high-carbon steels. Low-alloy structural steels are relatively easily welded, for which preference has hitherto been given mainly to manganese steel with up to 3% Mn. Nickel steels are frequently welded with unalloyed welding wire, the weld picking up so much nickel from the parent metal that the strength of the latter is approximately attained. This phenomenon has already been discussed in these columns.[4] Normalizing or stress annealing is desirable for all nickel and chromium-nickel steels. Frequently the parent metal is preheated to avoid cracking due to air hardening. If possible, steels of over 214,000 psi tensile strength should not be welded. Heat-resisting chromium-aluminum steels are particularly difficult to weld because both elements tend to burn away. These steels can be successfully welded only by oxyacetylene or atomic hydrogen; nevertheless the usual burning away of alloying elements must be taken into account. The welding of austenitic steels has been discussed on several occasions in these columns.[5]

The same question, especially the suitability of the different methods of welding for stainless steels is critically investigated by M. R. Moritz.[6] Good arc welds in any of the chromium steels are possible only with coated electrodes whose coating dissolves the chromium oxides that are formed; coatings containing blue and white asbestos with additions of cryolite, calcium carbonate and fluorspar have met with approval. The composition of the electrode must be such that loss by burning is taken into account. If the steel is hard to make, frequently only a part of the alloying constitu-

* W. Lohmann and W. Schneider, *Stahl u. Eisen*, **56** (11), 333–337 (1936). This report was translated by Dr. G. E. Claussen, research assistant to the Fundamental Research Committee. The translation is presented as a contribution of this Committee to the research workers and others interested.

[1] Symposium on the Welding of Iron and Steel (London: Iron and Steel Institute (1935)), Vol. II, 507–516.

[2] Symposium on the Welding of Iron and Steel, Vol. I, 513–526.

[3] Symposium on the Welding of Iron and Steel, Vol. II, 363–372.

[4] See E. Haardt, *Elektroschweissg.*, **5**, 161–164 and 193–196 (1934); *Stahl u. Eisen*, **55**, 992 (1935).

[5] See the last Review, *Stahl u. Eisen*, **55**, 992 (1935).

[6] Symposium on the Welding of Iron and Steel, Vol. II, 445–452.

ents is added to the electrode, the remainder being plated on. A pronounced hardening near and in the weld which leads to shrinkage cracks appears to an extent proportional to the chromium and carbon contents. Difficulties need not be feared, however, with low carbon contents. On account of the high resistance of chromium-alloyed electrodes, they should be as short as possible and the amperage as low as possible. The atomic hydrogen process, on the other hand, can be used for nearly all alloy steels, hardening in the transition zone being less than in arc welding. With correct welding, changes in carbon and silicon content only are possible. Welding defects in the form of pores and blow-holes occur by absorption of hydrogen by the melt and by too rapid solidification.

Further investigation of this matter was made by W. Andrews and W. C. Welsh[7] who studied chromium steels for pressure vessels at elevated temperatures. These steels have recently been introduced for petroleum cracking and hydrogenation apparatus where austenitic chromium-nickel steels, which are difficult to weld, cannot be used. The chromium steels with low carbon contents (0.15 to 0.2%) are particularly favored because they combine good physical properties with sufficient resistance to chemical attack.

For welding tubes and similar profiles the flash resistance process is mainly used. The defects encountered are slag inclusions in the weld and evidences of burning of parent metal which is shown by intercrystalline oxide concentrations. Chromium and chromium-nickel steels are especially sensitive to these defects. These defects are particularly annoying because they elude detection by the usual non-destructive testing methods; although ultra-short waves may possibly reveal these defects, no method as yet in use has been successful. Both types of defects greatly decrease strength and corrosion resistance.

Only the gas, arc and atomic hydrogen processes can be used to weld chromium steels that have high strength at high temperatures. The question of filler material is of prime importance for all processes. If chromium steel wire of the same chemical composition as parent metal is used, the weld does not have as good properties as the parent metal from the technological and chemical view-points even if the proper fluxing agent is used. Frequently, therefore, chromium-nickel steel wires are used, although, depending on the application, an attack of the weld itself may be expected in this case. In the reviewers' opinion, in those instances where nickel exerts a bad effect, it is best first to lay a bead with chromium steel wire, then lay the outside bead with austenitic chromium-nickel steel wire at once to get a tough weld. The burning away of alloying elements plays an important part in welding. Chromium, titanium and similar additions to improve chemical properties tend to oxidize. In gas welding, the welding wire may have an increased proportion of chromium or titanium to offset the loss by oxidation. This is also possible for chromium in arc welding, but an increase in titanium in electrode or coating causes welding difficulties.

All chromium steels have a tendency to dendrite formation which is not completely removed by heat treatment and is not at all removed by heat treatment in high-chromium steels. Nevertheless, chromium steels should be annealed to destroy any martensitic structure. All in all, there is still much room for developing steels which will completely satisfy the requirements of the petroleum industry from both the welding and the chemical standpoints.

[7] Symposium on the Welding of Iron and Steel, Vol. II, 307–316.

Andrew and Welsh also touched on the subject of corrosion. They expect special developments in high-frequency induction furnaces to make available high-alloy steels with very low carbon contents. Although by adding enough titanium, intercrystalline corrosion can be avoided, the ferrite thus formed in the austenitic chromium-nickel steels lowers the resistance to highly corroding liquids. Molybdenum, which raises the strength at elevated temperatures, reduces the resistance to superficial and intercrystalline corrosion.

The weldability of aircraft structural steels is dealt with by R. T. Taylor.[8] For gas welding the following is worth noting: manganese steels are easy to weld and have good physical properties, which, however, are not so high as those attained by low-carbon chromium-molybdenum steels, though the latter are not so good from the standpoint of weldability. Above all, Taylor recommends that the carbon content of the chromium-molybdenum steels should not exceed 0.25%. In manganese steels the danger of embrittlement on account of rapid cooling is great especially if the carbon content is about 0.3% and the manganese 1.75%.

The same problem is dealt with by J. Roosenschoon[9] who is particularly interested in welding cracks in aircraft steel. The good properties of high-purity, low-silicon mild steel have induced the Fokker works to use mild steel in their planes. A number of rules have been prepared to avoid stresses in the construction of airplanes. Stainless steels have been used only up to 0.7 to 1.2 mm. thickness but no difficulties have been encountered. The superiority of chromium-molybdenum steels from the standpoint of physical properties is admitted by Roosenschoon, but these steels have a tendency to crack in welding. The determining factor in the choice of material is the question of fatigue strength. Tests performed elsewhere showed that in the welded condition soft steel had a higher fatigue value than chromium-molybdenum steel. It is not known to what extent this agrees with service results. The author concludes that for simple joints chromium-molybdenum steel can be used without risk; for complicated structures more experience must be gained.

W. Hoffmann[10] deals with the weldability of steel tubes and their use in aircraft construction. As a basis for his experiments he used plain-carbon and alloy steels which to the reviewers' knowledge—at least as far as chromium-molybdenum steels are concerned—are not used in Germany in the analyses given. From his own and others' tests using different filler rods, Hoffmann deduces the causes of welding cracks. Considering the causes known at present Hoffmann finds that cracking does not occur if the material is free to move, if the carbon content amounts to 0.3%, and if the sulphur[11] and phosphorus together are greater than 0.07%. All previous experimental work in no way confirm—including Hoffmann's own experimental results—the favorable effect of carbon, sulphur and phosphorus; on the contrary the endeavor is usually made to keep the phosphorus as low as possible. A thorough study of the different variables is required to solve this problem.

H. Harris[12] reports new developments in electrodes. Oxygen and nitrogen, whose effects on welds have been discussed repeatedly, enter the weld against the will of the operator and exert a powerful effect on the properties of the weld. The way to avoid them in arc welding is to

[8] Symposium on the Welding of Iron and Steel, Vol. I, 459–464.
[9] Symposium on the Welding of Iron and Steel, Vol. I, 443–448.
[10] *Z. VDI*, **79**, 1145–1148 (1935).
[11] The original states silicon, which is a typographical error; see *Z. VDI*, **79**, 1486 (1935).
[12] Symposium on the Welding of Iron and Steel, Vol. II, 359–362.

use electrodes coated with mineral matter or, more recently, organic material. Part of the oxygen is derived undoubtedly from the coating, which does not exist as dissolved oxygen but as inclusions which exert an effect on the behavior of the weld. If these inclusions are distributed as a fine dispersion, they do not have a bad effect but act as nuclei and refine the grain structure. Nitrogen is harmful only above the solubility limit (0.015%); values below this limit can only be obtained with electrodes which contain additions of organic material. These coatings appear to be approved also for alloy electrodes since the coating prevents loss of alloy by burning; even metallic oxides in the coating can be reduced and carried into the weld. Despite this, these electrodes always produce a great decrease of carbon in the weld. Harris believes that this can only be possible by the reducing action of hydrogen in the protecting gas sheath.

2. Processes

The joining of steam pipes has come into the foreground with the recent requirements of high steam pressures and temperatures. Tests of welded pipes, especially at high temperatures and pressures, have been made by A. G. Bugden[13] with mild plain-carbon steel (about 0.15% C). The usual method is to weld on flanges but this is not approved by Bugden and is more troublesome than the kind of joint he proposes. The tubes to be joined are bulged out at the ends and butt-welded together after inserting a ring probably intended to make the welding easier. These joints in pipes 12 inches diameter, $1^1/_{16}$-inch wall, were tested at 400° and 430° C. with internal pressure between 1200 and 1350 psi and superimposed bending loads. For this purpose the pipe was filled with steam and externally heated by electricity. The duration of test was 90 to 1460 hours. The radial and longitudinal stresses in the pipe were computed from measurements of change in diameter. The creep stress was also computed. The tests show that safe pipe joints without flanges and bolts may be prepared in this way which have adequate safety for high-pressure steam piping.

O. M. Harrelson[14] studied the effect of hammering on shrinkage stresses. The same energy was delivered by each blow by gripping the hammer in a special apparatus so that the entire surface of the weld could be hammered. The only variable was air pressure which was found to be best at 155 psi. Shrinkage stresses were measured by Jennings' method.[15] An I-shaped cut in a plate was made by means of a torch; the web of the I was then welded. The stress was determined from the change in the distance between two holes in the gripped portion of the plate. The material used had a tensile strength of 48,500 psi, and was $1^3/_{16}$ inch thick. Bare, thin-coated and heavy-coated electrodes were used. The welds were of double-V type made by straight-line and weaving methods.

The highest shrinkage stresses, irrespective of the kind of welding, were found with bare electrodes, then heavy-coated; they were least with thin-coated dipped electrodes. In some cases the stresses considerably exceeded the nominal tensile strength of parent metal. Despite the apparatus for holding the hammer the stress decrease caused by hammering the cold weld varied considerably; with bare electrodes the decrease in stress produced by hammering was $^1/_2$ to $^1/_4$ the stress in the unhammered condition; with $^3/_{16}$-inch heavy-coated electrodes the decrease was 50%. By using thinner electrodes lower stresses were found in the unhammered condition; the decrease in shrinkage stress was then less on hammering than with $^3/_{16}$-inch electrodes. On the basis of his experiments Harrelson concludes that hammering causes a decrease in shrinkage stresses and an improvement in all physical properties. This is in agreement with other investigations; it must be remembered, however, that there are inherent sources of error in the method used by the author which limit the validity of the results and of the magnitude of the stresses concerned. The change in the position of the reference marks on welding cannot be considered a measure of the shrinkage stresses, because the deformations involved are plastic and involve no stress. For stresses only the change between the welded condition and the stress-free condition produced by cutting the specimen from the plate is important.

The high pressures involved in spot welding with copper electrodes cause a broadening of the electrode surface after a comparatively small number of welds. To avoid these deformations G. Komovski[16] recommends that the copper electrodes be enclosed in a cylindrical steel sheath which fits the electrode and gives it more rigidity. For this purpose a steel is used which has sufficient strength at 500° to 600° C. The relation between cross section of the new type of electrode and the amperage is shown in curves.

Surface welding for high wear resistance, especially for rails, is discussed by C. R. Déglon,[17] whose results show that it is not desirable to add alloying elements to the coating because the absorption of these elements by the bath depends on welding conditions, and uniform distribution is difficult to attain. The filler rod is so selected that weld material and rail have the same hardness; by hammering, the hardness can then be raised a further 50 Brinell. A good composition of filler rod is: 1% C, 0.7% Mn, 1.2% Cr which gives a weld containing 0.4% C, 0.6% Mn, 0.7% Cr. The hardness of the weld deposit varies with rail temperature between 300 and 450 Brinell. Thorough tests have shown that the rail should be preheated to higher temperatures in order to get better union and structure in the transition zone, and to avoid cracks which are not at all uncommon when surfacing cold rails. No significant improvement in structure is found up to 200° C. but above this temperature good results are obtained. Preheating should not be as high as 500° C. because notch-impact value at this temperature is greatly reduced, and then too the surfacing must be done without holding up traffic. Preheating is best and most uniformly carried out by induction currents, the necessary A.C. generator for which can be coupled directly to the welding generator.

3. Methods of Testing

The experiments of R. K. Hopkins on steels for pressure vessels for low temperature operation (petroleum dewaxers) have been discussed in an earlier review[18] where it was mentioned that nickel steels were best adapted. In a recent paper[19] Hopkins deals especially with the testing of such vessels. Usually the specifications require that the vessel pass a hammer test at sub-zero temperature during which no damage is done to the vessel. For this purpose the vessel is filled with petroleum, raised to the required pressure, and immersed in an oil bath cooled with CO_2 ice. After reaching the specified conditions the vessel is rapidly withdrawn from the bath and the welded seams are struck with a hammer. Another requirement is that the porosity must

[13] Symposium on the Welding of Iron and Steel, Vol. I, 187–197.
[14] American Welding Society Journal, **14**, No. 5, 19–25 (1935).
[15] American Welding Society Journal, **10**, No. 4, 27–30 (1931).
[16] American Welding Society Journal, **14**, No. 7, 14–15 (1935).
[17] Symposium on the Welding of Iron and Steel, Vol. II, 353–358.
[18] *Stahl u. Eisen*, **55**, 495 (1935).
[19] Symposium on the Welding of Iron and Steel, Vol. I, 243–258.

not exceed 2% of the plate thickness. Alongside the weld is placed a reference strip with holes so that comparison of blackening of the X-ray film gives a direct indication of the diameter of pores and slag inclusions. Experience has shown that these methods are extraordinarily good.

B. Ronay[20] describes a new method for testing electrodes during welding (Arconograph). The method is based on oscillographic testing of electrodes. The latter method showed that the number of drops is larger the higher the carbon content of an electrode, and this is true for bare as well as for dipped and coated electrodes. Drop transference takes place in two steps. During the first step the arc is characterized by relatively high voltage and low amperage. After a certain time a drop is formed and is flung from the electrode; a short circuit between electrode and parent metal then occurs characterized by high amperage and low voltage. Both steps are of fundamental importance in welding and with increasing duration of arc a greater part of the parent metal is pre-melted. On the other hand, the smaller the drops the better the penetration. The oscillogram is undoubtedly sensitive enough to show these conditions, but it has the disadvantage that the welding process cannot be observed on the spot; the film must be developed.

This disadvantage is remedied by the Arconograph; it merely shows the above-named steps as average values and does not reveal the fine details arising from voltage variations. The Arconograph consists of a grid-type tube with an ammeter of definite inertia. A current flows in the tube only if a definite grid voltage is impressed; that is, during the time of arcing. The ammeter in series with the tube shows average values of the recurring short circuits and arcing times on account of its inertia; with irregular recurrence of the cycle the variations are observed. The more uniform the throw of the needle of the ammeter, the more uniform is the welding, and the better is the weld. The examples given by the author showed no X-ray defects, but showed defects in the Arconograph which were indeed detected in the fractures of the specimens. A large number of measurements showed that with bare electrodes the arc occupied 50 to 61% of the total number of cycles, with coated electrodes 85 to 95%.

4. Properties of the Weld

The numerous tests performed during the last year on the fatigue strength of welds have shed much light on this topic, so that now we have enough information on the effect of shape and position of weld on permissible loads in fatigue.

In this connection experiments of foreign investigators are of special importance because they generally use different methods from our own. A. M. Roberts[21] tested welded specimens in reversed bending, plate cantilever type. In agreement with the results of German investigators, Roberts finds that welds with bare and coated electrodes do not differ fundamentally in fatigue behavior, and that fatigue strength is independent of welding process. The low fatigue strength of fillet welds as well as the undesirable effect of cover straps over butt welds is likewise confirmed. Machining, according to Roberts, improves the fatigue strength of gas and atomic hydrogen welds less than arc welds, which is undoubtedly explained by the better transition from weld to parent metal, especially with respect to undercutting, that is obtained with gas and atomic hydrogen welding.

[20] *J. American Society Naval Engineers*, **46**, 285–298 (1934).
[21] Symposium on the Welding of Iron and Steel, Vol. II, 831–841.

B. P. Haigh[22] studied the fatigue strength of welds in mild structural steel with special reference to the effect of defects, such as blow-holes and slag inclusion, on butt welds. High-grade V and double-V welds made with two kinds of coated electrodes (details not given) were tested in bend fatigue and direct-tension fatigue. It was first shown that the rotating bend specimens had the same fatigue strength as the specimens in alternating direct tension-compression. Specimens machined with the greatest care gave a maximum value of alternating bend fatigue strength of about 25,600 psi, whereas porous welds (no information was given as to the size of pores although the specimens corresponded to commercial welds) gave only about 12,800 psi. Porous welds gave an alternating direct tension-compression fatigue limit of 12,800 to 15,700 psi, machining having no effect on account of the preponderating effect of the porosity. Poor penetration was much more injurious; for such specimens Haigh found fatigue limits in alternating direct tension-compression of less than 7100 psi. Unwelded spots at the root of double-V welds had a similar effect. Service tests on a pressure vessel with a wall thickness of $1^3/_{16}$ inch showed that even with porous welds the safety of welds in fatigue is not so low as is frequently assumed; the first crack appeared after 320,000 cycles at a cirumferential stress of about 21,400 psi.

The applicability of welding to the chemical industry is discussed by N. P. Inglis and W. Andrews[23] with special reference to corrosion of the weld and heat-affected zone in the parent metal. The authors believe that welding has not yet advanced so far that high-pressure vessels can be manufactured with absolute safety by welding and that the seamless drum still holds the field. For low and medium pressures (up to 100 psi) the welded vessel is quite safe. The greatest expectations are placed, however, on the welding of tubes and pipes. The application of welding to medium alloy steels usually leads to the difficulty that grain refinement cannot be obtained by heat-treatment, but requires mechanical work unless austenitic welding rods are used. In this last case, however, pronounced corrosion occurs in the parent metal. Frequently in parts that must be resistant to hydrogen, a bolted joint is used with thin welded seams to assure tightness. The intercrystalline corrosion question in corrosion-resistant steels has frequently been discussed. We merely mention the author's opinion that a titanium addition prevents intercrystalline corrosion; however, titanium favors the appearance of ferrite islands in the austenite. Carbides separate in the ferrite and not in the grain boundaries. These steels are less satisfactory against extremely corrosive liquids, the attack being concentrated in the immediate vicinity of the weld.

Supplementing earlier investigations[24] on the magnetic properties of arc and atomic hydrogen welds, W. F. Hess and R. L. Ringer[25] carried out tests on gas welds. Vanadium, nickel-vanadium, silicon and plain-carbon steel filler rods were used. The plain-carbon weld was superior in permeability and watt loss to the vanadium and nickel-vanadium steel rods. The silicon welds gave best magnetic properties at about 2% Si; they gave the best magnetic properties of all the welds tested. Annealing for 2 hours at 1000° C. increased the permeability and decreased the watt loss in all specimens. The degree of improvement was greatest in the silicon and plain-carbon welds. The best properties with plain-carbon

[22] *The Welder*, **7**, 548–552 (1935).
[23] Symposium on the Welding of Iron and Steel, Vol. I, 259–265, and *The Welder*, **7**, 566–570 (1935).
[24] American Welding Society Journal, **13**, No. 10, 21–24 (1933).
[25] American Welding Society Journal, **14**, No. 6, 18–21 (1935).

welds are obtained by gas welding; with silicon welds the atomic hydrogen and gas processes are best.

The chemical changes undergone by the filler rod in melting in the arc are investigated by J. H. Paterson.[26] Nitrogen pick-up precedes the formation of iron oxide, and he found up to 0.5% nitrogen in the brown deposit occurring in the weld with bare electrodes; on further welding this enters the melt and gives rise to oxygen and nitrogen pick-up. It is the author's opinion that nitrogen pick-up occurs principally in this way but he does not deny the possibility of other mechanisms. He further showed that the increase in hardness during carbon arc welding was due to carbon pick-up from the electrode.

The explanation of spattering in gas welding lies in the easily-reducible oxides in the welding wire, according to E. Streb and H. Kemper.[27] They assume that dissolved and undissolved ferric oxide is reduced by reaction with hydrogen and that the gas evolution causes spatter. In this connection silica and alumina have no effect. Furthermore, tests with a variety of filler rods showed that spatter was increased by too low manganese content, whereas silicon up to 0.1% decreased spatter. The phenomenon causes blow-holes and slag inclusions and consequently low physical properties in the weld, which is revealed especially in low tensile strength and elongation. The following experiment of the authors shows that a spattering wire has been insufficiently deoxidized: by melting the wire and deoxidizing it with manganese the spattering, though not entirely eliminated, is considerably decreased; deoxidation with silicon completely eliminates spatter. The silicon content should not be too high lest other difficulties be met. High phosphorus and sulphur have a bad effect, which can scarcely be detected however up to 0.04% S and 0.05% P. On this basis Streb and Kemper formulate requirements for gas welding wires. Experiments on the weldability of steel St 52 were made using different welding wires. Best results were obtained with nickel and nickel-chromium-molybdenum steel wires of the following composition:

% C	% Si	% Mn	% Cu	% Cr	% Ni	% Mo
0.10	0.18	0.49	0.15	0.66	2.14	0.14
0.15	0.26	0.56	0.15	0.10	3.43	..

With these wires notch impact values were obtained equal to St 37.

The practicability of flame cutting for preparing parts to be welded is discussed by C. G. Bainbridge and E. J. Clarke.[28] Comparison was made between machined vees, good torch cuts and low-grade torch cuts made with excess oxygen. Heavy-coated electrodes were used for some tests, thin-dipped electrodes for others. The physical properties, including notch-impact value and bend angle, were determined on the welded specimens. The results show that torch cutting, whether good or bad quality, has no effect on physical properties of the weld, if heavy-coated electrodes are used. With dipped electrodes, torch cutting has a bad effect on physical properties. These differences are related to the capacity of the slag for dissolving iron oxide, the amount of slag being the important variable. From the standpoint of ease of welding there was no difference between good and bad torchcut and machined surfaces. This is also true for overhead and vertical welding. The composition and amount of slag are undoubtedly the important factors for the properties of the weld, but more detailed information on this point is not available.

Welding wires for hot-welding cast iron generally have a higher silicon content than the parent metal, thereby giving a machinable weld with high graphite content, according to L. J. Tibbenham.[29] He recommends that soda (neutral sodium carbonate) be added to the welding powder in order further to improve the graphite structure. The surface of the wire must be of good quality and free from sand inclusions. The quality is better in horizontally cast rods than in vertically cast. The graphite content of the welding wire affects the quality of the weld. For this purpose annealing for $1^1/_2$ hours at 950° C. followed by sand blasting is recommended.

5. Service Behavior

Accidents to welded pressure vessels and their causes are discussed by F. E. Pollard.[30] The defects are divided into the following groups:

1. Poor penetration,
2. Incorrect location of the weld,
3. Faulty assembly of parts of the boiler,
4. Metallurgical defects.

The first defect is frequently found where butt welds cannot be reverse welded or inspected. Faulty assembly means that no opportunity for inspection of welds is provided. The correct location of welds has already been discussed in these columns.[31] The accidents due to metallurgical defects were caused mainly by improper heat treatment, according to Pollard. Basic rules for avoiding these defects are given in British Standard Specification No. 487.

A series of papers has appeared recently dealing with the use of welding in rail joints and building up worn rail ends in heavy traffic sections. Ashworth and May[32] investigated the applicability of various methods but give new information only for arc welding. A plate is placed under the foot of the rail, and a joint plate is placed up to the top of the rails and between their ends. The rail is preheated to 230° C. and the head of the rail welded with a wire containing 0.35% C, 1.3% Mn and 0.4% Cr. Then the joint plate is secured to the web of the rail by T welds, while the gap between the feet of the rails is packed with a mixture of bitumen and sand. No great reliability can be claimed for this system because, of 700 such joints in a single-track division, seven fractured after some time in operation.

Foreign developments in rail improvement are summarized by J. Staebler.[33] The cost of materials and process is much less for gas than for arc welding, so that, considering the superiority of the gas-welded product, this method is preferable, according to the author. Three methods may be used to build up rail ends according to the type of traffic: (1) Rail ends simply broadened out; (2) non-uniform wear caused by uni-directional traffic; (3) uniform wear caused by traffic in both directions. In the first case it is frequently satisfactory simply to heat the rail ends with a torch and forge them back to shape. In the other two cases surfacing by welding must be carried out. Worn rails with more than 0.12-inch wear are best replaced. Chromium-vanadium-molybdenum steel is used as filler rod for surfacing; a high-carbon, high-manganese steel is sometimes recommended. To produce a wear of 0.06 inch on a surfaced rail, a rolling load of 41 to 57 million tons is necessary, according to American information.

[26] *The Welder*, **7**, 514–515, 547 and 575 (1935).
[27] Symposium on the Welding of Iron and Steel, Vol. II, 573–591.
[28] Symposium on the Welding of Iron and Steel, Vol. II, 321–331.
[29] *Sheet Metal Ind.*, October 1934, 599–602.
[30] Symposium on the Welding of Iron and Steel, Vol. II, 825–829.
[31] L. W. Schuster, *Proc. Instn. Mech. Engrs.*, I, 319–418 (1930); see *Stahl u. Eisen*, **51**, 1063–1065 (1931).
[32] Symposium on the Welding of Iron and Steel, Vol. I, 299–306.
[33] *Autog. Metallb.*, **27**, 195–201 (1934).

6. General

A. Portevin and D. Séférian[34] investigated to what extent Fry's iron-nitrogen diagram up to 0.5% can be applied to welds. Their specimens were prepared partly in the usual arc, partly by melting in the atomic nitrogen arc. Dilatometric measurements showed that the end of the eutectoid horizontal does not lie at 0.5% N_2 but at about 0.14% N_2, so that the nitride eutectoid occurs in steels above 0.14% N_2. A constituent that looked like Braunite was actually observed in bare electrode welds by W. Lohmann and E. H. Schulz.[35] The eutectoid horizontal placed by Fry at 580° C. is now said to lie at 590° C. The solid solubility limit of nitrogen at room temperature was not determined. Above the eutectoid line the diagram is given a new interpretation which however is of slight importance from the welding standpoint.

An investigation of the economic advantage of adding illuminating gas to acetylene was made by E. Streb and H. Kemper.[36] Theoretical considerations showed that with the same rate of flow, an addition of 30% illuminating gas makes possible a saving of only 20% acetylene, because pure acetylene has a greater oxygen requirement than illuminating gas. Flame temperatures were therefore 20% lower. With constant oxygen content the proportion of acetylene can be reduced only 2% by adding 30% illuminating gas, so that only a small decrease in temperature is to be expected. The theoretical calculations were confirmed by practical tests on bare iron plates in which the time of melting of the material and the distribution of temper colors were noted. There is, therefore, no basic economic advantage in adding illuminating gas to acetylene.

[34] *Rev. Soud. Autog.*, **27**, No. 251, 12 (1935).
[35] *Arch. Eisenhüttenwes.*, **7**, 470 (1933–34).
[36] *Autog. Metallb.*, **27**, 293–297 (1934).

Translation of Important Foreign Articles Relating to Welding

The Fundamental Research Committee of the AMERICAN WELDING SOCIETY in cooperation with the Engineering Foundation Welding Research Committee is seeking to establish a procedure for making available to the research workers of this country, the knowledge and experience abroad gained as a result of expensive research work. It is rare to find instances of any adequate recognition on the part of American publishers of technical and engineering books and magazines of the importance of these activities in foreign countries. Consequently, the F. R. C. is seeking to establish a cooperative arrangement among a limited number of companies and individuals for making translations and supplying them in sufficient number so that they can become available to those who desire them.

It is planned to make the central office of the AMERICAN WELDING SOCIETY the clearing-house for this information. Although no definite plans have been worked out for making these copies available, it is suggested that any reader who believes from its title that the translation of a particular paper would be of value to him should write to Mr. W. Spraragen, Technical Secretary of the AMERICAN WELDING SOCIETY, and it should usually be found practicable to provide him with a copy, either on loan or permanently. Already Mr. Spraragen has the particulars of a matter of 100 translations of articles on welding and he is acquainted with the routine of making these available on loan, or, when the interest is sufficient, by mimeographing a supply of copies.

Individuals and companies are cordially invited to communicate with Mr. Spraragen or the writer if they desire to participate in this cooperative arrangement and indicate whether they are able to make translations, do mimeograph work or in other ways contribute to its effectiveness.

H. M. HOBART, *Chairman*

There follows a list of translations of important articles now available.

List of Translations Available

Article	*Author*	*Magazine*
"Strength of Machine Elements as Dependent on Their Shape"	By August Thum and Wilhelm Bautz	*Stahl und Eisen*, Vol. 55, No. 39, pp. 1025–1029, Sept. 26, 1935.
"Krupp's Special Welding Method According to German Patent 567,-094"	By E. Beckmann	*Technische Mitteilungen Krupp*, No. 4, V. 3, August 1935, pp. 137–142.
"Influence of Welded Seams of Highly Alloyed Welding Material on the Life of Boiler Plates"	By C. Carius	*Technische Mitteilungen, Krupp*, No. 4, V. 3, August 1935, pp. 173–175.
"Progress in the Technique of Welding in the First Half of 1934"	A review by Wm. Lohmann	*Stahl und Eisen*, **54**, 1934, 1212–1216.
"Stresses in Welding" (Only one copy available)	By Dipl. Ing. E. Helfrich, Halle a. d. Saale	*Die Wärme*, Vol. 55, No. 39, Sept. 24, 1932.
"Results of Fatigue Strength Tests on Welded Connections"	By Dr. Ing. Kommerell	Publications of the International Association for Bridge and Structural Engineering, third volume, 1935, pp. 230–270.
"On Stresses in Welds" (Only one copy available)	By Dipl. Ing. A. Sonderegger, Zurich	*Zeitschrift für Schweisstechnik*, **1933,** No. 3 and No. 4.
"Contribution to the Question of Welding Stresses" (Only one copy available)	By Dr. Ing. Hans Bühler and Dr. Ing. W. Lohmann	*Die Elektroschweissung, Braunschweig*, Vol. 5, No. 8, August 1934, pp. 141–145.
"On the Effect of Small Admixtures in the Welding Wire on the Welding of Copper"	By Wilhelm Geldbach	*Autog. Metallb.*, **24,** 319–331, 335–345 (1931) (145th Communication from the Metallurgical Laboratory of the Technical College, Berlin — Prof. Dr. W. Guertler
"Stresses in Welded Seams" (Only one copy available)	By Prof. L. v. Roessler	*Autogene Metallbearbeitung*, Vol. 26, No. 18, Sept. 15, 1933, pp. 273–279.
"Thermal Stresses in Welded Bars" (Only one copy available)	By K. Melcher	*Elektroschweissung*, Jan. 1933, pp. 7–9.

NOTE: Where only one copy is available the AMERICAN WELDING SOCIETY will be glad to lend it for a limited time.

THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

Sponsored by American Welding Society and American Institute of Electrical Engineers

Two-Day Session of Welding Engineers and Scientists Held at Watertown Arsenal

The Subcommittee on Industrial Research of The Engineering Foundation Welding Research Committee held a two-day session, July 23–24, at Watertown Arsenal, Watertown, Massachusetts. Colonel G. F. Jenks, Commanding Officer of the Arsenal and Chairman of the Subcommittee, presided at the various sessions.

The function of the Subcommittee on Industrial Research is to make a survey of industrial welding research activities under way, contemplated and desired, and to provide an organization to correlate these activities to the advantage of the welding industry.

Colonel Jenks stated that the purpose of the conference was to complete the organizations of the Sub-subcommittees preliminary to the analysis of research activities being conducted to solve the many complicated problems in the welding field. Colonel Jenks pointed out that this work was of great importance to all branches of the metal working industry including governmental departments, railroads, shipyards, automotive, aircraft structures, buildings, bridges, and pressure vessels.

The work was divided among various Sub-subcommittees including the following Material Sub-subcommittees: I. Cast Iron—(Chairman not yet named); II. Carbon Steels—J. C. Hodge, *Chairman;* III. Low-Alloy Steels—J. H. Critchett, *Chairman;* IV. High-Alloy Steels—T. H. Nelson, *Chairman;* V. Aluminum Alloys—G. O. Hoglund, *Chairman;* VI. Copper Alloys—D. K. Crampton, *Chairman;* VII. Nickel Alloys—O. B. J. Fraser, *Chairman.*

Three Functional Sub-subcommittees are being organized: A. Methods of Testing—M. F. Sayre, *Chairman;* B. Analysis of Weld Failures—(Chairman not yet named); C. Weld Stresses—Causes and Effects—E. Chapman, *Chairman.*

The two-day session included the presentation of papers and reports on radiography, monel metal, low-alloy steels and high velocity impact tests. Members of the Subcommittee had an opportunity to witness various welding operations at the Arsenal, the centrifugal casting of low-alloy steel, and the testing of metals under impact loads delivered at the rate of more than 300 ft. a second. Mr. H. C. Mann, in charge of the work on impact testing, stated that he had found that almost every metal had a critical transition velocity at which its ability to withstand impact loads fell off very sharply. Through the results of these tests the Arsenal was able to select those materials which were best suited for the various services encountered in Ordnance work.

The Lynn Works of the General Electric Company acted as host to the eminent group of scientists and engineers and demonstrated the wide applications of welding in the construction of all types of dynamo electric machinery and boilers.

A second conference is planned for the middle of October in Cleveland during the Annual Convention of the AMERICAN WELDING SOCIETY and the Metal Congress Exposition.

Dr. C. A. Adams, Chairman of the Welding Research Committee, reported that The Engineering Foundation had made three grants totaling $12,000 to launch the project and that leaders of industry had pledged whole-hearted cooperation.

There follows a list of the present membership of the Subcommittee on Industrial Research:

*Jenks, Col. G. F., *Chairman,* Commanding Officer, Watertown Arsenal, Watertown, Massachusetts
*Adams, C. A., Professor, Harvard Engineering School, Harvard University
Bibber, L. C., Carnegie-Illinois Steel Corporation
Boardman, H. C., Research Engineer, Chicago Bridge and Iron Works
Brophy, G. R., Research Laboratory, General Electric Company
Bureau of Construction and Repair, Navy Department
*Chapman, E., Vice-President, Lukenweld, Incorporated
*Crampton, D. K., Research Director, Chase Brass & Copper Company, Incorporated
*Critchett, J. H., Vice-President, Union Carbide and Carbon Research Laboratories
*Crowe, J. J., Engineer in Charge of Apparatus, Research and Development Department, Air Reduction Company
Eksergian, C. L., Chief Engineer, Budd Wheel Company
*Farmer, F. M., Vice-President and Chief Engineer, Electrical Testing Laboratories
*Fraser, O. B. J., Superintendent, Technical Service, The International Nickel Company, Incorporated
French, H. J., In Charge, Alloy Steel and Iron Development, Development and Research Department, The International Nickel Company, Incorporated
Gibson, A. E., Vice-President, Wellman Engineering Company
Halsey, W. D., Assistant Chief Engineer, Boiler Division, The Hartford Steam Boiler Inspection and Insurance Company
*Hobart, H. M., Chairman, Fundamental Research Committee; Consulting Engineer, General Electric Company
*Hodge, J. C., Chief Metallurgist, The Babcock & Wilcox Company
*Hoglund, G. O., Welding Engineer, Aluminum Company of America
Jasper, T. M., Director of Research, A. O. Smith Corporation
Jennings, C. H., Research Laboratories, Westinghouse Electric and Manufacturing Company
Jennison, H. C., Technical Manager, The American Brass Company
Johnson, J. B., Chief, Material Section, Wright Field
Kidd, A., Works Manager, The M. W. Kellogg Company
Lincoln, J. F., President, The Lincoln Electric Company
*Llewellyn, F. T., Research Engineer, United States Steel Corporation
Loos, C. E., American Bridge Company
Miller, H. L., Metallurgical Department, Republic Steel Corporation
Moore, G. H., Jr., Welding Engineer, Welding Office, Production Department, Newport News Shipbuilding and Dry Dock Company
*Nelson, T. H., Consulting Metallurgist, Research Laboratories; Officer-in-Charge, Specification Section, Design Division, Bureau of Engineering, Navy Department
*Sayre, M. F., Professor, Department of Applied Mechanics, Union College
Schenck, C., Engineer of Development, Bethlehem Steel Company, Incorporated
*Spraragen, W., Secretary, Welding Research Committee
Wallace, L. W., Director, American Railway Research Advisory Committee
Weigel, A. C., Combustion Engineering Corporation

* Executive Subcommitee Members.

Translations

Through the courtesy of one of the cooperating companies of the Committee, there are available two copies of translation "Stress Measurements on Welded Circular Seams," by Dr. Ebel and Dipl. Ing. Reinhard, M. Gladbach, translated from *Autogene Metallbearbeitung,* Vol. 27, Oct. 1, 1934, no. 19, pp. 305–310. The AMERICAN WELDING SOCIETY will be glad to loan these copies upon request.

A limited number of copies of translation made by another cooperating company are available for distribution. "The Welded Plate Girder," by Dr. Ing.

Karl Schaechterle, Berlin, translated from *Der Bauingenieur*, April 17, 1936, pp. 131-137.

A few copies of a translation from *Stahl und Eisen* of an article by Karl Ludwig Zeyen, entitled "Welding of Steels of Higher Strength," Vol. 55, No. 34, are available. Copies may be obtained on request.

A limited number of copies of translation from *Technische Mitteilungen Krupp, 3, Jahrgang, Heft. 4*, August 1935, pp. 176–188, of an article by K. L. Zeyen, entitled "The Welding of High Strength Steels" are available for distribution. Copies may be obtained on request.

Fundamental Research Committee Activities

The Fundamental Research Committee, under the Chairmanship of Mr. H. M. Hobart, is revising its bulletin listing current fundamental research problems in welding needing solution. As in former issues, the bulletin will include a list of professors engaged in fundamental research work in the welding field, some sixty in number, and the problems upon which they are working.

In order to facilitate this important research work, the Committee has prepared a brief review and digest of the welding literature relating to research here and abroad. This review, covering the period January 1935 to June 1936, approximately, is divided into the following main headings:

- Effect of Carbon on the Properties of Fusion Welds in Steel
- Effect of Silicon on the Properties of Fusion Welds in Steel
- Effect of Manganese on the Properties of Fusion Welds in Steel
- Welding Cast Iron
- Welding Alloy Steels
  - (*a*) Low-Alloy Steels
  - (*b*) Stainless and Related Alloy Steels
  - (*c*) Alloy Steels at the British Welding Symposium
- Welding Non-Ferrous Metals
  - (*a*) Copper and Nickel
  - (*b*) Zinc and Lead
  - (*c*) Aluminum (General)
  - (*d*) Aluminum (Processes)
  - (*e*) Aluminum (Alloys and Castings)
- Modulus of Elasticity of Austenitic Welds in Mild Steels
- Resistance Welding Electrodes
- X-rays in Welding
- Corrosion of Welds
  - (*a*) Methods of Corrosion Testing and General Results
  - (*b*) Results in Special Materials
- Metal Transfer in Welding and Allied Topics
  - (*a*) Metal Transfer in the Arc
  - (*b*) Magnetic Blow and Generator Characteristics
  - (*c*) Physics of the Arc
  - (*d*) Gas
- Weld Shrinkage
  - (*a*) Theoretical and Experimental
  - (*b*) Shrinkage from the Field Standpoint
- Stress Distribution in Welded Joints

This report is available in mimeograph form. Copies will be mailed to all who request them. It is expected that this first draft will undoubtedly bring forth valuable criticism and comment which will be helpful in revising the final edition of the bulletin and its publication in printed form.

Another conference of professors interested in welding research is to be held October 20th, in Cleveland, during the time of the Annual Meeting of the Society. About twenty professors have signified their intentions to attend.

The following reports will be presented as formal papers before the Annual Meeting of the Society.

- "Heating by the Proximity Effect," by Edward Bennett, University of Wisconsin
- "Impact Tests of Welds at Low Temperatures," by Otto Henry, Brooklyn Polytechnic Institute
- "Characteristics of a Universal Welding Generator," by N. F. Ward, University of California
- "Welded Beam-Column Connections," by Inge Lyse, Fritz Engineering Laboratory, Lehigh University
- "Welded Structural Brackets," by C. D. Jensen, Lehigh University

The Committee has been active in securing national cooperation in making available translations of important foreign articles on welding research. A list of available translations was published in the June issue of this Bulletin, and a supplementary list is given elsewhere in this issue. The names of the companies and individuals who are cooperating in this plan are given below. Others are invited to lend their cooperation. Each company or individual is asked to cooperate to the extent of making two translations a year, or to furnish 100 copies of a translation made by another. In some instances some companies have kindly offered to do both.

W. E. Crawford—Translations
A. O. Smith Corp.

J. H. Critchett—Translations and mimeograph
Union Carbide & Carbon Research Labs.

J. J. Crowe—Translations and mimeograph
Air Reduction Company

A. F. Davis—Mimeograph
Lincoln Electric Company

A. S. Douglass—Translations
Detroit Edison Company

F. Eder—Translations
Robert W. Hunt Company

F. M. Farmer—Mimeograph
Electrical Testing Laboratories

F. H. Frankland—Translations and mimeograph structural work
American Institute of Steel Construction

W. F. Hess—Mimeograph
Rensselaer Polytechnic Institute

H. H. Henline—Mimeograph
American Institute of Electrical Engineers

H. M. Hobart—Translations and mimeograph
General Electric Company

C. J. Holslag—Translations
Electric Arc Cutting & Welding Co.

C. H. Jennings—Mimeograph
Westinghouse Elec. & Mfg. Co.

D. S. Jacobus—Translations
Babcock & Wilcox Company

F. T. Llewellyn—Translations (French) and mimeograph
U. S. Steel Corporation

E. L. Mills—Translations
Bastian & Blessing Company

Critical Digest of Welding Literature

A number of professors and others interested are assisting the Welding Research Committee of The Engineering Foundation in making available comprehensive critical digests of the world's welding literature on specific subjects.

In this way, a digest of the literature on Impact Resistance of Welded Joints (up to January 1936) has been made available, and there will soon appear digests of the literature relating to Fatigue Properties of Welded Joints, and the Welding of Copper and Its Alloys. A considerable number of tables relating to Resistance Welding have been compiled and will be issued in mimeograph form.

Activities of the German Welding Committee

Literature

Short critical abstracts of technical articles, papers, patents and books on all phases of welding published in all countries of the world are now being issued in mimeograph form each month by the Welding Committee of the VDI (German Society of Engineers). The abstracts are made by members of the Literature Subcommittee of the German Welding Committee (Subcommittee Chairman is Dr. W. Adrian), and are sent free of charge to any member of the VDI who requests them. All abstracts of articles published in a given month are assembled in a single sheet which is ready for delivery in the succeeding month. Abstracts are thus made available as soon as possible after the articles themselves are published. Articles published in German periodicals are mentioned by title only, with occasionally brief comments on their contents. The German welding periodicals are not abstracted. Articles in non-German periodicals are abstracted at length (200 words) with occasional brief criticisms.

In addition, the Committee reprints each month all reviews of books on welding appearing in German periodicals, and issues a semi-annual subject and author index to their abstracts. During the first six months of 1936 about 140 articles were abstracted, of which only about 25 were non-German. Included in the abstract sections is a section on the practical application of welding in design.

Research

The official publication of the German Welding Committee is called Zwanglose

Mitteilungen (Occasional Communications) of which No. 29 (12 two-column pages) was published in July 1936. At the Committee Meeting on May 7, 1936, the following proposed research problems were discussed.

1. Determination of shrinkage stresses in long seams welded Step-Wise. (The arc welding division of the Committee was requested to finance this research.)
2. Determination of the effect of shrinkage stresses on creep strength at elevated temperatures. (Financed by gas and arc divisions with support of State Railways.)
3. Investigation of the effect of number of layers in thick seams on quality, shrinkage, shrinkage stresses, structure and mechanical properties. (Arc and gas divisions.)
4. Determination of the effect of preparation of scarf on mechanical properties of welded joints. (Of particular interest in pressure vessels and in parts subjected to fatigue.)
5. Fatigue Tests of Stainless Steels. (The program of tests must be more definitely outlined; the Alloy Steel Sub-Committee is delegated to prepare a review of literature.)
6. Systematic Investigation of all brands of electrodes from the standpoint of evolving gases dangerous to health. (The Committee is not interested in problems of ventilation but merely in the chemical constituents of electrodes, filler rods, fluxes and coatings.)

Problem No. 63 of the Gas Welding Subcommittee entitled "The Gas Welding of Chromium-Nickel Steel Plates," is still in progress.

The Subcommittee on Deformation discussed the DIN-DVM 121 Standard Bend Test and added the following:

In testing welded joints in plates less than 5 mm. thick (0.2 inch) a special standard will be prepared. For this test strips are used with radii similar to the tensile specimen, Sheet A120, Fig. 2.

A long discussion (2 pages) on the free-bend test, the tensile test of welds parallel to the seam, the Blomberg cruciform tensile test, and forgeability tests is given. (Further information given elsewhere in this bulletin.)

Subcommittees

Reports of the following Subcommittees are also given.

Group 1. Apparatus (*a*) Gas (*b*) Arc
Group 2. Materials
Group 3. Methods of Testing
Group 3(*a*). Methods of Arc Welding
Group 3(*b*). Methods of Gas Welding
Group 4. Personnel (Instruction)
Group 5. Signs and Symbols
Group 6. Safety
Group 7. Literature
Group 8. Promotion (Research)
Group 9. Welding of Steel
Group 10. Welding of Non-Ferrous Metals
Group 11. Welding of High-Strength Steels
Group 12. Design (including a discussion of the new DIN4101E Standard Specification for Welded Plate Girder Steel Highway Bridges)
Group 13. Welding in Machinery Construction
Group 14. Standards
Group 15. Raw Materials
Group 16. Spreading of Facts
Group 17. History of Welding

The publication is concluded by announcements of technical lectures on welding in Berlin, Vienna, etc. (with abstracts of some of the lectures) and by a section of General Topics and Announcements in which the proposed Review of the World's Welding Literature by the Welding Research Committee (U. S. A.) is given in full (Books I–IV). "A magnificent plan; we hope it is completed."

Standard Tests

The German Welding Committee has been instrumental in promulgating the following recent Standard German Tests for Welds:

Tensile Test	DIN-DVM A120	October 1935
Bend Test	DIN-DVM A121	October 1935
Notch Impact Test	DIN-DVM A122	April 1936

Activities of the Subcommittee on Methods of Testing of the Welding Committee of the German Society of Engineers (VDI)

(Translated by G. E. Claussen, Research Asst. Welding Research Committee from: Zwanglose Mitteilungen des Fachausschusses für Schweisstechnik im VDI No. 29, July 1936.)

Subcommittee 3. Methods of Testing.
Sub-subcommittee on Tensile Test.

The tentative standard DIN-DVM 120 on the Tensile Impact Test for Welded Joints has been published for criticism by the Committee. The standard will probably be issued in final form in July 1936.

Sub-subcommittee on Ductility.

Meeting March 13, 1936, at Hanover.

1. Bend Test: The tentative standard DIN-DVM 121 on the Bend Test for Welded Joints was issued for criticism by the Committee. The replies were discussed at a Committee meeting, March 13, 1936. The new wording will probably be issued as a standard in July 1936. At the suggestion of the Central Office of the Prussian Boiler Inspection Society the Committee resolved:

"A special standard is being prepared for testing welds in plate less than 5 mm. (0.20 inch) thick. In this test the specimens have the same radii as the standard tensile specimens Fig. 2, Standard Sheet A120."

2. Free-Bend Test: The free-bend test does not have so high a scatter as the results of the ordinary bend test. Although the free-bend test takes longer to perform and requires complicated apparatus, it has the advantage that the weld, transition zone and parent metal are subjected to a uniform bending moment so that the joint fails at its weakest point.

It had been suggested that experiments be made on homogeneous specimens of suitable brittleness to determine the percentage scatter associated with the free-bend apparatus. For this purpose Dr. Mailänder presented a comprehensive outline of tests which were performed on homogeneous specimens of 0.5% C steel in various types of heat treatment using for one set the free-bend apparatus, for a companion set the usual pin-and-roller bend equipment.

The most important result of the tests was that the free-bend test did not give a uniform elongation over the gage length. Furthermore, maximum elongation did not always occur in the middle of the gage length. In the harder specimens, which gave the lower bend angles, the free-bend test gave higher values of ductility than

the pin-and-roller test. In the softer specimens, which gave the higher bend values, both tests gave more nearly the same results. In the pin-and-roller test the larger pin diameters gave more uniform distribution of elongation than the smaller. The tests showed that the free-bend test gave better differentiation between heat treatments than the pin-and-roller test.

In discussion, several gentlemen suggested to Dr. Matting (Chairman) that the whole complex question should be made the subject of a research, and for the present the question should be left open for expression of opinion. A plan of research is to be drawn up and then those concerned will be notified.

Concluding the discussion on free-bend test *vs.* pin-and-roller test, Mr. Koch described the bend tests specified in the Hungarian and Australian codes, and proposed that any new research should consider the types of test used in these countries. In the Australian test a welded-on surface bead is bent around a roller $1^1/_2$ inches diameter whose axis is perpendicular to the bead. The elongation of the bead, which is stressed in tension as a consequence of bending, must be from 12 to 25%. The Hungarian test differs from the German in that the root side of the V weld is not acted on by a pin or punch. Instead a small pin acts on each side of the weld and at a short distance from the weld. The region between the pins is therefore subjected to a uniform bending moment. The root side of the specimen is machined out to a depth of 4 mm. (0.16 inch) and to a breadth of 15 mm. (0.59 inch). The Hungarian test thus shows a tendency toward the free-bend test.

3. Longitudinal Tension Test: Mr. Koch gave a brief review of the present status of the longitudinal tension test for welds (in which a V weld is pulled in tension, the load being applied in the direction of the weld). He also gave the following summary of tests recently carried out at Wittenberg.

(*a*) The following variables have no detectable effect on the value of elongation: breadth and length of specimen, scarf angle and proportion of weld metal to parent metal. The breadth was varied between 21 and 50 mm. (0.83 inch to 2.0 inches), the proportion of weld metal between 20 and 38%.

(*b*) Specimens 20 mm. (0.79 inch) thick gave several per cent less elongation than specimens 10 mm. (0.39 inch) thick.

(*c*) Specimens without reinforcement gave 2 to 3% higher elongation than with reinforcement in all the parent metals, filler rods and welding methods investigated.

(*d*) In arc welds the elongation was almost independent of parent metal and was determined by electrode and method of welding. A small deviation from this was observed in gas welds.

(*e*) The following table summarizes the results:

Method of Welding and Filler Metal	% Elongation With Reinforcement	% Elongation Without Reinforcement
1. Coated electrode, annealed	25	...
2. Gas welds	18 to 25	22
3. Coated electrode, unannealed	14 to 18	18 to 19
4. Bare electrode	6 to 7	7 to 9
5. Light dipped electrode	5	6 to 8
6. Cored electrode	4 to 5	6 to 8

4. Blomberg Test: (In this test described by Blomberg, H., *Elektroschw.*, **6,** 61–67 (1935), the ductility of a welded T joint in tension is judged by the appearance of a rectangular mesh scribed on the cross section of the joint.) Mr. Koch first gave a brief description of the test and the advantages claimed by Blomberg, which are:

(*a*) The ductility of a welded joint as it actually occurs in structures is measured. No special, artificial specimen is required.

(*b*) In contrast to the bend test, the ductility can always be observed to the point of fracture.

(*c*) The flow of metal during the test is made visible by a mesh of lines, which shows at once to what extent the weld and adjacent areas share in the deformation;

(*d*) In contrast to the bend test, the ductility of the root of the weld is also determined.

(*e*) The test determines tensile strength, yield strength and elongation at fracture on a single specimen.

In brief the Blomberg method cooperates with the requirements of practice in that the center of interest of the test is the joint between weld metal and parent metal. The test shows the behavior of the joint throughout the whole test as if plotted on graph paper.

After receiving expressions of opinion for and against the Blomberg test, a plan of research will be drawn up.

5. Testing the Forgeability of Welds: Mr. Koch summarized a paper by Dr. Becker on this topic which appeared in *Autog. Metallb.*, page 193 (1935). Of special interest to the Sub-subcommittee are the numerical values assigned by the author to different degrees of forgeability. The higher the forgeability number, the more difficult is the test that must be passed. Three types of specimens are used by Becker:

Specimen A includes Forgeability Nos. 0–4.
Specimen B includes Forgeability Nos. 5–9.
Specimen C includes Forgeability Nos. 10–12.

Specimen A: Two plates 10 x 30 mm. (0.39 inch x 1.18 inches) are welded together. Weld and transition zone over an area of 5 x 20 mm. (0.20 inch x 0.79 inch) are then forged at a temperature of 1050 to 950° C. The forged part is then twisted 360° over a length of 120 mm. ($4^3/_4$ inches). The forgeability number is determined with the aid of the following table:

Forgeability No. 0 weld breaks during forging
Forgeability No. 1 weld does not break during forging
Forgeability No. 2 weld cracks a great deal during twisting
Forgeability No. 3 weld cracks a little during twisting
Forgeability No. 4 weld does not crack during twisting

Specimen B: A specimen welded like Specimen A is bent at 1050 to 950° C. so that the face of the weld is in tension, the root being on the inside of the bend. Weld and transition zone are then forged out to the form of a tongue, the tongue part being turned over several times, so that both sides of the tongue are struck.

Forgeability No. 5, many cracks in the weld during bending
Forgeability No. 6, a few cracks in the weld during bending
Forgeability No. 7, no cracks in the weld during bending
Forgeability No. 8 cracks at the edge of the forged tongue
Forgeability No. 9, no cracks at the edge of the forged tongue

Specimen C: A weld having Forgeability No. 9 is acceptable in practice. Specimen C may therefore be omitted. On two plates 10 mm. (0.39 inch) thick lain next to each other a weld bead 20 mm. (0.79 inch) wide, 10 mm. (0.39 inch) high, and 100 mm. (4 inches) long is deposited, the width of the bead being attained by moving the filler rod back and forth. The specimen is then bent at 1050 to 950° C.

Forgeability No. 10, many cracks during bending
Forgeability No. 11, a few cracks during bending
Forgeability No. 12, no cracks during bending

The author's tests showed that no weld failing at a low number could pass at a higher forgeability number. The scatter for a series of welds made under the same conditions never exceeded one forgeability number.

(*Continued on page 16*)

The Metallurgy of "Pure" Iron Welds

By GILBERT E. DOAN* AND WILLIAM C. SCHULTE†

AN EXTENSIVE program of investigation is being carried out at Lehigh University in the study of arcs and arc welds of high-purity iron,[1] sponsored by the Engineering Foundation. The part of that program reported in the present paper deals with welds made of high-purity iron in an argon atmosphere and for comparison with them welds made of the same iron in ordinary air. Welds of commercial steel also were made in argon and in air. The primary purpose of the study is to discover the basic physical constants of iron welds when not contaminated either by impurities in the iron or by the action of oxygen and nitrogen of the air during welding. Upon these constants can be founded such future studies as will determine what effects the various impurities and alloy elements present in steel have upon its welding characteristics, and what influence is exerted by the action of oxygen and nitrogen.

The welding of steel involves such a multitude of variables, both of composition and of procedure, that development in the fabrication of this most important metal has necessarily been slow, wasteful and, in many instances, discouraging. In the present investigation, the simplest possible condition has been selected; namely, iron practically free from contamination and a nonparticipating atmosphere, the inert gas argon. This simplification reduces the number of variables to a point where more rigid control of the system is possible.

* Associate Professor of Metallurgy, Lehigh University, Bethlehem, Pa.
† Research Metallurgist, Lukens Steel Co., Coatesville, Pa. Recently Engineering Foundation Fellow at Lehigh University.
Presented before February 1936 Meeting, American Institute of Mining and Metallurgical Engineers. A contribution to the Fundamental Research Committee of Engineering Foundation.

Although this study is significant for the contributions it makes to the science of steel fabrication, yet it is hoped that it will not be without value also in increasing knowledge of the nature and behavior of iron and steel in general. From the standpoint of open-hearth practice, and to some extent from the standpoint of electric-furnace practice also, the conditions of melting and casting iron in this investigation are extraordinary. The casting temperature is high, the mean temperature of the metal probably reaching 2000° C. (3600° F.).[2] The rate of chilling of this metal in the "mold"—that is, in the metal object being welded—is unusually rapid. The argon atmosphere, especially after the first few seconds of welding, is extremely pure. And the iron, both that of the electrode and of the plate, is of high purity. The "castings" produced under these new conditions may behave in ways that ultimately will enable us to understand more fully some of the many idiosyncracies of iron and steel produced in present-day tonnage programs.

In passing it may be remarked that the arc itself is found to be quite a new phenomenon under these conditions of high purity. For example, it will not exist if the purity of the gas is carefully guarded, but rather goes out as soon as it is struck. The crater under the arc, the feature that is called "penetration" by the welder, simply does not exist under these conditions. Hence, welding is impossible. These aspects of the investigation have been described elsewhere; also the apparatus and the methods employed to obtain the welds.[1] The present account deals with the metallurgical features of the metal before and after deposition by arc welding.

Table 1—Compositions and Physical Properties of Wires and Welds

	Statement of Carbonyl Iron Manufacturers, Per Cent	Hydrogen Treated Carbonyl Iron, Per Cent	Iron Deposited in Argon on Iron Plate, Per Cent	Covered Iron Deposited in Air on Iron Plate, Per Cent	Iron Deposited in Air on Iron Plate, Per Cent	Iron Deposited In Argon on Steel Plate	Covered Iron Deposited in Air on Steel	Iron Deposited in Air on Steel Plate	Steel Welding Wire E No. 1 A, Per Cent	Steel Deposited in Argon on Steel Plate, Per Cent	Covered Steel Deposited in Air on Steel, Per Cent	Steel Deposited in Air on Steel Plate, Per Cent
C	0.016	0.009	0.007	0.022	0.005				0.046	0.014		0.025
Mn	0.000	0.026	0.006	0.005	0.006				0.11	0.120		0.091
P	0.000	0.010	0.004	0.025	0.004				0.006	0.006		0.006
S	0.000	0.005	0.004	0.004	0.005				0.021	0.027		0.023
Si	0.000	0.002	0.003	0.18	0.003				0.002	0.004		0.090
N_2		0.002	0.006[b]	0.017	0.098				0.003	0.015[b]		0.172
O_2	0.01	0.002	0 006	0.152[c]	0.265[d]				0.036	0.012		0.276[e]
H_2		0.0002	0.0008	0.0009	0.003				0.0004	0.0006		0.005
Physical Properties												
Ultimate strength, lb. per sq. in.		29,800	40,600	58,400	65,600	47,100	56,200	62,800		Too	64,900	60,100
Yield strength, lb. per sq. in.			23,400	43,900	38,100	24,200	41,400	37,750		porous	43,200	45,600
Elongation, per cent in 3/4 in.		[a]	29.4	12	4	27	14	5		for	23.3	10
Reduction of area, per cent		100–	90	15	3.5	95	15	5		test	30	6.3

[a] Plastic flow obliterated gage marks. [b] Nitrogen values include argon. [c] An average of two individual values: 0.160 and 0.143. [d] An average of two individual values: 0.259 and 0.270. [e] An average of two individual values: 0.244 and 0.344.

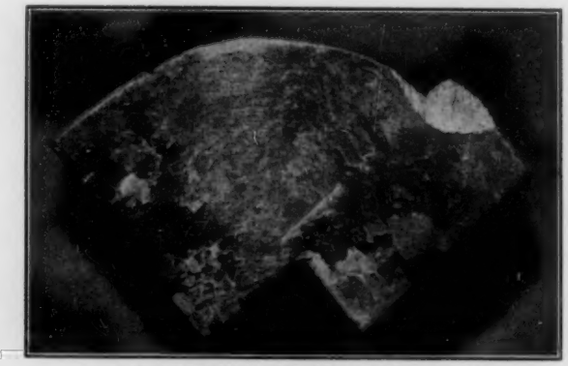


Fig. 1—Iron Weld in Argon on Iron Plates. X3

Materials Used

The wires and plates used in this program were of carbonyl iron obtained from the I. G. Farbenindustrie, Ludwigshafen, in May 1933. This material is formed when the gas iron carbonyl is heated, somewhat like the action of nickel carbonyl in the Mond process. The analysis given by the manufacturer is: sulfur, phosphorus, silicon, manganese, 0.000 per cent; carbon, 0.016 per cent. The oxygen content was understood to be below 0.01 per cent. In view of the extraordinary magnetic properties obtained by Cioffi[3] when the final traces of impurities are removed from iron by hydrogen treatment just under the melting point this material was subjected to a similar treatment. Through the cooperation of Dr. S. Dushman, at the General Electric Laboratories, both the wire and the plates were heated in a stream of undried hydrogen for 72 hr. at temperatures between 1375 and 1420° C. This treatment was effective in reducing the oxygen from 0.01 to 0.002 per cent and carbon from 0.016 to 0.009 per cent, as shown in Table 1. During treatment at this high temperature, an undesirable contamination of the iron occurred, however. The manganese and phosphorus contents rose, the contamination apparently coming from the refractories that lined the furnace, although all physical contact of specimens and lining was avoided. Thus the purity of the iron, like that of all "pure" iron material, leaves something to be desired. It was the best obtainable. Some untreated iron was reserved for comparative tests. The chemical analyses throughout this work were carried out through the cooperation of Dr. Anson Hayes, of the American Rolling Mill Company.

The wires were 4 mm. thick; the plates 2 mm. and 6 mm. Bare wire, cleaned of all drawing compound, was used in most of the tests. In a few instances it was coated to produce a "shielded arc" such as has recently yielded commercially a weld metal of markedly superior properties. The coating contained cellulose with sodium silicate as a binder and some titanium oxide to reduce porosity and to stabilize the arc electrically. These rods were coated for us by the cooperation of the A. O. Smith Corporation. The iron plates were used to line a 90° V-groove between two steel plates each $^1/_2$ in. thick, the plates serving as "backing" to prevent the arc from melting through the thin iron lining and to diminish magnetic blowing of the arc.

The argon was obtained from the Incandescent Lamp Department of the General Electric Co. As received, the gas contained approximately 1 per cent nitrogen. Carbonaceous gases were below 30 parts per million. The argon was given final purification by a misch-metal discharge, and when analyzed before use showed a purity of 99.3 to 99.6 per cent. The first few seconds of welding raised this purity considerably, owing to the scavenging action of the iron vapor coming off in large volume from the welding arc. The composition of the steel welding wire used for comparisons is given in Table 1. The wire was contributed by the Page Steel and Wire Company.

All welding was done by an automatic machine,[1] not by hand. Since no penetration was possible when welding in argon, multilayer welding was out of the question and single-layer welds were used. A layer was made as thick as possible by slow travel of the welding table. Nevertheless, specimens smaller in size than the standard had to be used. The tension specimens were $^1/_4$ in. in diameter at the ends, undercut to $^3/_{16}$ in. on the shank of the specimen. To obtain values for elongation that would be comparable to those obtained with the standard 0.505-in. round specimen, the formula $l = 4.5\sqrt{A}$ was used to compute the proper gage length. This computation gave a gage length of approximately 0.75 in. The welds made in air were multipass welds but the tension specimens were cut to the same size, nevertheless, so that all test results would be comparable.

The Welds

Chemical Compositions

Welds in Argon.—The compositions of the wires and welds are given in Table 1. The welds are not homogeneous chemical samples, but vary somewhat, especially those made in air. The individual values are given as footnotes to the table. When welding with iron in argon, perhaps the most significant change to be noted is the slight rise of oxygen content of the metal from 0.002 to 0.006 per cent. It indicates that the argon was not perfectly pure, in spite of the precautions exercised. The apparent rise of nitrogen when welding in argon from 0.002 to 0.006 for iron (and from 0.003 to 0.015 for steel) is probably apparent only. Since the vacuum fusion method used for chemical analysis does not differentiate between nitrogen and argon probably most of the gas reported as nitrogen in the argon welds was argon. Separate determination of nitrogen by the Allen method is under way but not yet completed. A substantial loss of manganese and phosphorus from the iron appears to take place when welding in argon. In this relatively pure inert gas, it seems that impurity elimination from the electrode wire may be a matter of differential evaporation rather than oxidation, although a little oxygen is present. Hydrogen rises from 0.0002 to 0.0008.

Fig. 2—Steel Weld in Argon on Steel Plates. X3

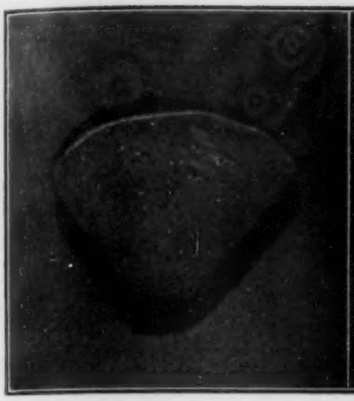


Fig. 3

Fig. 4

Fig. 3—Steel Weld in Argon on Steel Plates. X3

Fig. 4—Iron Weld in Air on Iron Plates. X3

The steel welds in argon, aside from the "argon" pickup, show a reduction from 0.036 oxygen in the wire down to 0.012 per cent in the weld, and a substantial reduction in carbon (0.046 to 0.014). This reduction probably occurs as a CO evolution. The porosity of these welds, shown in Figs. 2 and 3, may be attributed to this gas evolution.

Welds in Air.—The pure-iron welds in air differ little in composition from those in argon except for the high gas content of the air welds. Nitrogen is 0.098, oxygen 0.265, and hydrogen 0.003 per cent, all very high indeed. The steel welds in air are characterized by an even higher gas content: 0.172 nitrogen, 0.276 oxygen and 0.005 hydrogen. For some reason, the silicon is up also. The hydrogen probably comes from decomposed atmospheric water vapor.

Covered Welds in Air.—The covered-iron welds are in general intermediate with respect to those made in argon and those made in air. Nitrogen is excluded by the coating better than oxygen. Thus nitrogen is 0.006 in argon, 0.017 in covered-wire welds, and 0.098 in air, showing about 85 per cent exclusion. Oxygen, evidently from the coating, rises from 0.006 in argon to 0.152 in covered-wire welds and to 0.265 in air, showing only about 60 per cent exclusion by the covering. The covering raises the carbon, phosphorus and silicon in the welds, by chemical reduction of the coating. It appears to lower the manganese. Comparative figures for covered-steel welds are not yet available.

Macrostructure

In Argon.—A single-layer deposit of iron in argon is shown in Fig. 1. The sharp line of separation between weld and plate resulting from the absence of crater formation and penetration noted above is visible, although partly obscured in preparation of the specimen. This weld is entirely free from porosity. With drastically purified argon, the welds are entirely sound. When the purity drops, slight porosity is encountered in the iron welds. Also, when the carbonyl iron wire (0.01 per cent oxygen) was used without hydrogen purification, the welds in purified argon were porous. This seems to indicate that the presence of very little oxygen, either in the wire or in the atmosphere of the arc, will result in porosity.

In order to investigate thoroughly the lack of penetration observed in argon welds, a considerable number of experiments were carried out using the cheaper steel wire and plates. The analysis of the steel is given in Table 1. Every combination of arc length, current, welding speed and wire manipulation conceived of was tried without once obtaining effective penetration; that is, crater formation. Figure 2 shows a multilayer weld of this kind, the section being taken near the beginning of the layer. Owing to the slight degree of impurity of the argon at the beginning of the weld, slight penetration is shown in the lowest layer, but upon completion of almost every weld of this kind the connection of weld to plate was so limited that the entire weld could be lifted out of the groove with the fingers. The surfaces of each layer were silvery bright, with no indication of any slag or oxide layer to obstruct crater formation by the arc. Nevertheless, no crater formed. Figure 3 shows a single-layer weld. It was lifted out of the V without difficulty, because of the absence of penetration.

Gas cavities are numerous in these welds and it will be noted that the contours of these cavities are smoothly rounded. Changing the welding current within the entire range from 60 to 180 amp. was ineffective in eliminating porosity. In an attempt to keep the weld metal

Fig. 5

Fig. 6

Fig. 5—Steel Weld in 90 Per Cent Argon and 10 Per Cent Air. X3

Fig. 6—Iron Weld in Air on Iron Plates. X3

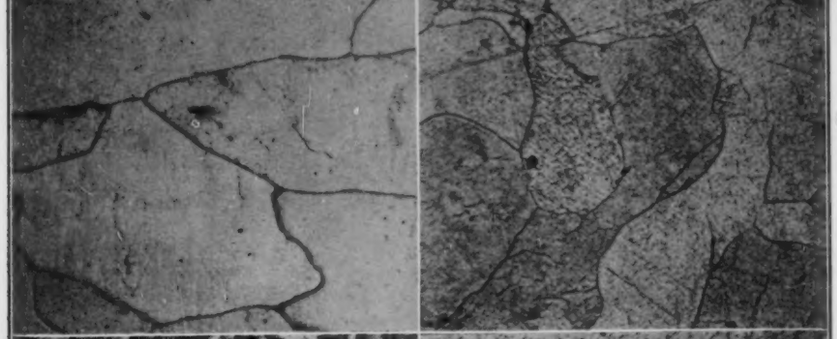


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Fig. 7—Iron Weld in Argon, as Welded. X180

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Fig. 8.—Iron Weld in Argon, Annealed at 600° C. X180

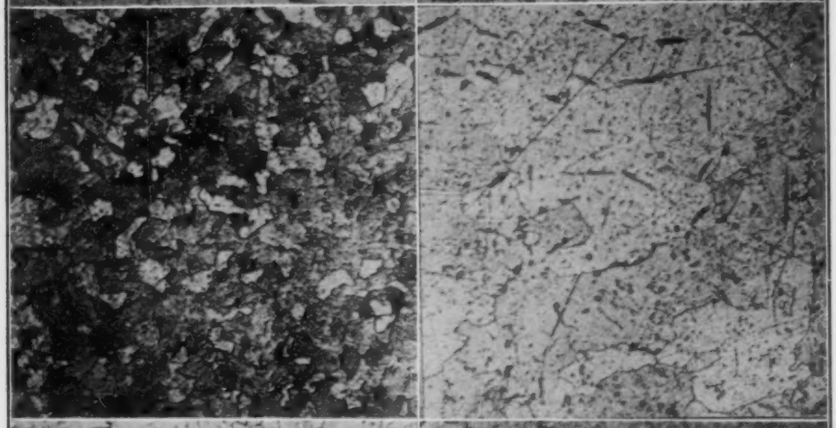

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Fig. 9—Iron Weld in Air, as Welded. X180

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Fig. 10—Iron Weld in Air, Annealed at 600° C. X180

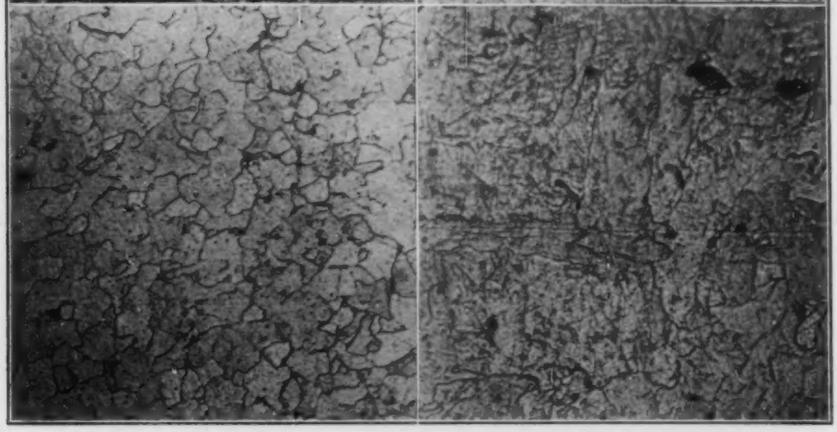

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Fig. 11—Covered-Iron Weld in Air, as Welded. X180

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Fig. 12—Covered-Iron Weld in Air, Annealed at 600° C. X180

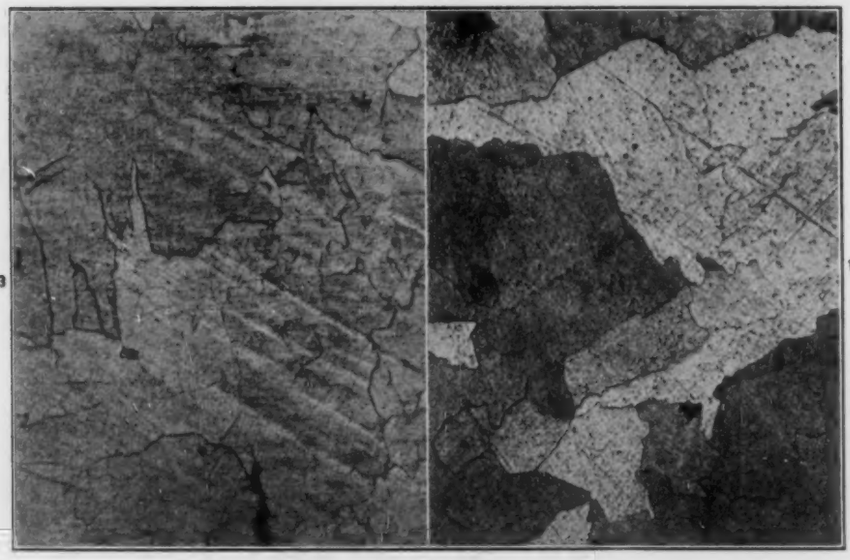

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Fig. 13—Steel Weld in Argon as Welded. X180

Fig. 14—Steel Weld in Argon, Annealed at 600° C. X180

molten long enough to permit escape of the gases that caused this porosity, very thin sheets of base metal were used instead of the thicker plates, but without success Because of this prevalent porosity, no physical tests of these welds were made.

In Air.—When air replaces argon, the iron welds reveal the ordinary crater formation and ordinary penetration as shown in Fig. 4. The gas cavities are somewhat more angular. Such cavities probably would be far more effective as "stress raisers" than the smooth ones found in argon welds, and would show lower strengths. The structure of steel welds in air is quite familiar and is not shown here.

Interest in the lack of crater formation in argon led to trying various admixtures of air with the argon. A mixture of 50 per cent argon, 50 per cent air gives about the same penetration as does air. With 90 per cent argon, 10 per cent air, a substantial penetration can still be noticed (Fig. 5). There was a shallow crater at the end of the layer, indicating that very little air is necessary for crater formation. The cavities are predominantly angular.

Covered Wires.—When a cellulose-base coating covers the iron wire, penetration is still not prevented (Fig. 6). Porosity seems, if anything, more pronounced than in the unshielded welds. The cavities are angular also. The macrostructure of welds of covered steel wire is not illustrated.

Microstructure

Iron.—Large-grained ferrite, apparently pure, is the characteristic microstructure of the iron in argon welds (Fig. 7). Annealing this metal at 600° C. in hydrogen for 7 hr. to break down supersaturation and approach the equilibrium state produces very little change (Fig. 8) except in the veining of the ferrite. The grain size is perhaps slightly smaller, but not definitely so. It would be difficult to identify any of the impurities present, although analysis shows 0.007 carbon and 0.006 oxygen. The specimens were, of course, sectioned to avoid the surface effect of the hydrogen anneal, slight though it may be at this low temperature and for this short time.

When iron is welded in air, the case is quite different. In the as-welded condition the structure is one of quite small ferrite grains (Fig. 9) pretty well peppered with inclusions. The correlation of oxygen and nitrogen with grain size reminds one of the conditions usually found in open-hearth steel. After annealing (Fig. 10), the grain size is large, the "pepper" (probably oxide particles) is clearly visible and with it an abundance of nitride needles. This structure corresponds with the chemical composition of 0.098 per cent N_2 and 0.265 per cent O_2.

The cellulose-coated wires gave weld metal intermediate in grain size, "pepper" and nitride needles to that obtained in argon and that obtained in air, corresponding with the intermediate amounts of oxygen and nitrogen in the metal (Table 1). The structures of coated iron welds before and after annealing are shown in Figs. 11 and 12.

Steel.—When steel is welded in argon, large-grained ferrite, apparently pure, is again obtained (Fig. 13). The grains seem to have rougher, more acicular boundaries than those of pure iron. But when annealed (Fig. 14), this ferrite shows a considerable quantity of "pepper," which may be oxide particles (O_2 = 0.012 per cent) but practically no nitrogen (N_2 + A = 0.015 per cent), corresponding again to the chemical composition of the metal. The grain size is large, both before and after annealing. The microstructure of steel welds, both coated and uncoated, in air are well known and are not reproduced here. In general, the microstructures correspond with that indicated by the chemical compositions.

Strength

Iron Welds.—The strength of the pure-iron welds in argon is very low and is in conformity with their high purity and coarse grain size. Thus, 23,400 is the yield point and 40,600 lb. per sq. in. is the tensile strength (Table 1).

The strength data of Duftschmid, Schlecht and Schubardt[4] for carbonyl iron are: ultimate strength, 28,000 to 40,000 lb. per sq. in.; yield point, 15,000 to 24,000. Annealed electrolytic iron[5] averages 40,000 to 55,000 ultimate strength and 20,000 to 25,000 yield point, while vacuum-fused and annealed electrolytic iron shows 35,000 to 40,000 tensile strength with 10,000 to 20,000 yield point. The strength of hydrogen-treated carbonyl iron, before welding, that is, 29,800 (Table 1), corresponds to the low region of the German values 28,000 to 40,000. The welds of this iron in argon, however, are much stronger; i.e., 40,600 and 47,100. Some of the increase no doubt is attributable to the slight oxygen pickup in argon, some to rapid quenching and some to grain-size difference.

If these welds are made in air instead of in argon, the yield point is raised from 23,400 up to 38,100, and the tensile strength is raised from 40,600 up to 65,600 lb. per sq. in., again giving a clear revelation of the important influence of ordinary air during welding upon the properties of the weld metal. It seems clear that when made in air the strength of mild-steel welds, like those of pure iron, may also be due primarily to the action of the oxygen and nitrogen absorbed by the metal, and only secondarily to the chemical composition of the wires.

Of the greatly increased strength of iron welds in air (38,100 yield point; 65,600 ultimate strength) over those in argon (23,400 and 40,600) a part may be attributed to grain size. The argon welds have an average grain size of 29 grains per square millimeter; the air welds, 385 grains per sq. mm. This finer grain size might account for as much as 4000 or 5000 lb. per sq. in.[5] of the total rise of 25,000.

When the pure-iron wire was deposited upon mild-steel plates (0.17 per cent C), the results, both in argon and in air, were not essentially different from those obtained above with pure-iron plates. Naturally, since no craters form in argon, there was practically no penetration of the arc into the steel plates and little or no contamination of the weld by the plate stock was possible. For these results, see Table 1.

The coated-iron weld has risen in tensile strength from 40,600 for argon up to 58,400. The grain size is 230 grains per sq. mm. Owing to contamination of the weld by the coating, several elements are greater in amount in the weld than in the wire. The yield point of the covered-iron weld (43,900) is actually higher than that of the iron weld in air (38,100). Also, it is higher than that of the covered-*steel* weld in air (43,200), noted below. Too much emphasis cannot be laid upon the exact quantities denoted by these figures, however, for, as noted above, the welds are not entirely uniform in character and averages of a large number of specimens were not available.

Steel Welds.—When steel welds were attempted in argon, the weld metal obtained was so porous (Figs. 2 and 3 and noted above under *Macrostructure*) that it made tests uncertain in meaning; hence none are reported.

In ordinary air, the steel welds show the usual strength values; namely, about 60,000 lb. per sq. in. tensile strength and 45,000 yield strength. The steel welds were made from electrodes containing 0.046 per cent C

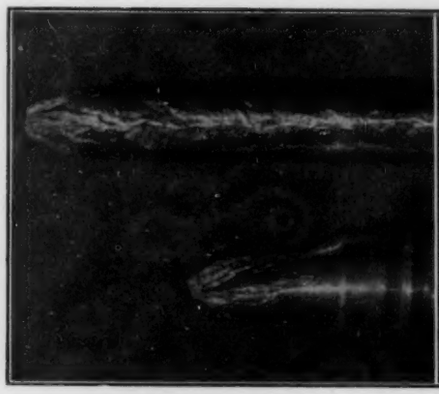

Fig. 15—Iron Weld in Argon

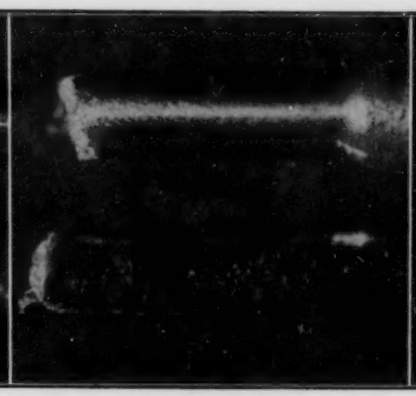

Fig. 16—Iron Weld in Air

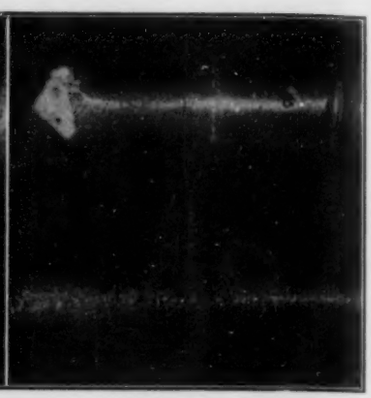

Fig. 17—Covered-Iron Weld in Air

and 0.11 per cent Mn, and after welding 0.172 N_2 and 0.276 O_2. It would seem that these welds should be much stronger than the iron welds, but actually they are not as strong. The strength of the covered-steel welds (64,900) is above that in air (60,100), probably because of pickup from the coating. The yield point is slightly lower.

Plasticity

Iron.—The plasticity of iron welds in argon—i.e., 30 per cent elongation and 90 per cent reduction—indicates what is achievable when air is excluded. When the iron is welded in air the plasticity drops to 4 per cent and 3.5 per cent, showing the amazingly strong effect of gases in the weld on the plasticity. When the iron is coated, these values rise only part way to the high plasticity obtained by the extensive protection of an argon atmosphere. They rise to 12 and 15 per cent.

Steel.—Comparing the plasticity values for iron welds in air (4 and 3.5) with those of steel welds in air (10 and 6.3), it is clear that the alloys in the steel have exerted a beneficial effect on its plasticity. When the steel is given additional protection by coating, these values rise to 23.3 and 30 per cent. But when the pure iron is coated, its plasticity values rise, as noted above, only to 12 per cent elongation and 15 per cent reduction of area, just about one-half that of steel with the same coating. The proportionate rise for iron and for steel after coating is about the same, it is true, but the small amount of alloys in the steel seems to exert almost as great an effect in raising the plasticity values (from 4 and 3.5 for pure iron up to 10 and 6.3 for steel) as does the coating, which raises it again from 10 and 6.3 up to 23.3 and 30. This is quite conceivable. But why the coating should benefit steel welds so much more than it benefits pure iron welds is not at first entirely clear. The analysis of the coated-steel welds when available may indicate the reason for their superiority over welds of coated pure iron.

Figures 15, 16 and 17 show the fractured tensile specimens. The roughened external surface of the pure iron specimen made in argon (Fig. 15) shows that the ductility of the metal is very high; also, the elongation takes place throughout the entire test length. The great reduction of area, 90 per cent (Table 1), is evident from the sharp point to which the bar is drawn at the point of fracture. Note in contrast the square end of the specimen welded in air (Fig. 16), which shows very little reduction of area (3.5 per cent) and very little elongation (4 per cent). The destruction of plasticity in the weld by the action of air during welding is clearly shown here. The covered-iron weld has a somewhat greater amount of ductility and reduction of area than that of the uncoated-wire welds, but the ultimate in shielding action seems by no means to be attained with the coating used in these tests. Specimens of steel welds are not shown.

Age-Hardening of Weld Metal

The weld specimens were subjected to quench-aging treatments. Hardness readings also were taken on the metal in the as-welded condition as soon as possible after the specimen could be prepared, which was a maximum of 20 min. after welding was completed. In the quench-aging tests, specimens of the welds were heated to 525° C. in a lead bath and quenched in iced brine; hardness readings were taken at intervals after the treatment (Fig. 18 and Table 2). The curves show that no age-hardening was detected in pure-iron welds made in argon, but that the welds made in air, both with the bare wire and the covered wire, age-harden substantially; owing, no doubt, principally to the nitrogen content.

Table 2—Complete Age-Hardness Data

Hardness after Welding		Hardness after Quenching	
Time Elapse	Hardness, Rockwell B	Time Elapse	Hardness, Rockwell B
Iron Weld in Argon			
19 min.	37–38–39	2.5 min.	40–40.5
30 min.	36	7.5 min.	40–39
1.5 hr.	37	12.5 min.	41–38.5
7.5 hr.	38	17.5 min.	41
17 hr.	38.5	27.5 min.	39.5
25.5 hr.	37	47.5 min.	40–41
96 hr.	37	3 hr.	40
840 hr.	37	552 hr.	39–38.5
Iron in Air			
17 min.	80–79	4 min.	64
71 hr.	82–80	7 min.	71
506 hr.	82	11 min.	79
792 hr.	84	27 min.	84
		5 hr.	83
		30 hr.	85
		78 hr.	88.5–90
		245 hr.	92
Covered Iron in Air			
19 min.	68	5 min.	60
1.25 hr.	68–71	10 min.	65
19.5 hr.	76.5–76	25 min.	65
91.5 hr.	75.5–78	5 hr.	65–67
263 hr.	82–84	30 hr.	71–69
698 hr.	80–82	78 hr.	71
		270 hr.	73

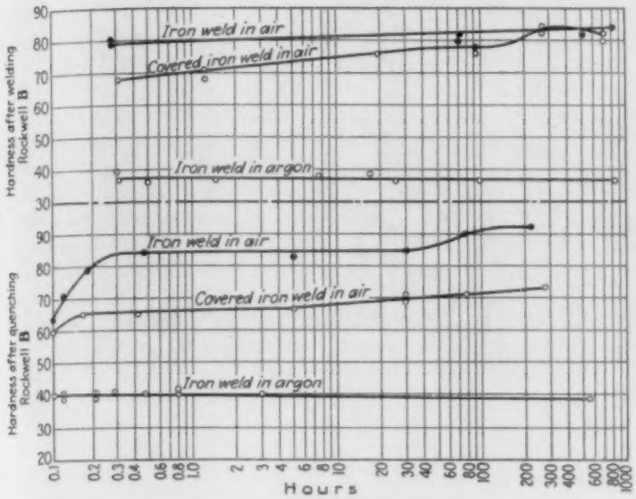
Iron weld in air
Covered iron weld in air
Iron weld in argon
Iron weld in air
Covered iron weld in air
Iron weld in argon
Hardness after welding Rockwell B
Hardness after quenching Rockwell B
Hours

Fig. 18—Aging Results

Summary and Conclusions

1. The impurities in the iron appear to be removed by *differential evaporation* in the arc in argon. Oxygen is not necessary for their removal.

2. The properties of the weld metal, especially its plasticity and formability, are changed profoundly by the action of the air upon the metal during welding. The oxygen and nitrogen contents of the metal rise sharply.

3. The metalloids (C, Mn, Si, etc.) in steel exert a protective action during welding in air and preserve a part of the formability of the metal.

4. Cellulose coating is partially effective in preserving the formability of pure iron welds in air. It is more effective on steel than on pure iron. But it is not fully protective even on steel.

5. Steel welds in argon are porous. Iron welds are not. All welds in argon lack "penetration" or crater formation.

6. The grain size of iron welds seems to depend upon the oxygen content of the metal.

7. The iron welds in argon show no hardness increase following quench-aging.

Acknowledgment

For suggestions out of which grew the original program of this investigation, acknowledgment is due to Dr. S. L. Hoyt.

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Proposed Impact Test Specimen*

By A. VOGEL†

IT IS proposed to develop a method of testing fillet welds using the Charpy impact testing machine. Three objects are sought: (1) A measure, in foot-pounds, of the resistance to failure by impact applied perpendicularly to the longitudinal axis and parallel to and 1-in. above the lower surface of one of the legs of the fillet weld, (2) determination of penetration into the root of the weld and, (3) determination of porosity and other characteristics of the fractured surface by visual examination.

The determination of the impact resistance in foot-pounds provides a measure by which various electrodes, welding methods, etc., may be compared. It may be possible to show a relationship between this impact resistance and the ductility or toughness of the weld metal deposited. The impact load is applied in such manner as to break the fillet weld specimen in its weakest plane, thus permitting comparison of weld metal deposits with respect to their weaker elements.

The broken specimen can be inspected for weld penetration into the parent metals at the root of the weld, determining whether or not the parent metals are fused together or whether the bond which exists at the root is only that of the deposited metal. If such penetration has any value, with respect to increased resistance to fracture, this test should bring out the relative merits of the various electrodes and methods.

Porosity has been claimed to be a serious element of weakness of certain methods of welding. It has been observed that fillet welds, which are slightly porous at the root of the weld, are frequently extremely tough. Whether the method of welding which produces a porous weld also produces a tough weld has not as yet been determined. This impact test, however, should indicate whether a small percentage of porosity results in weak-

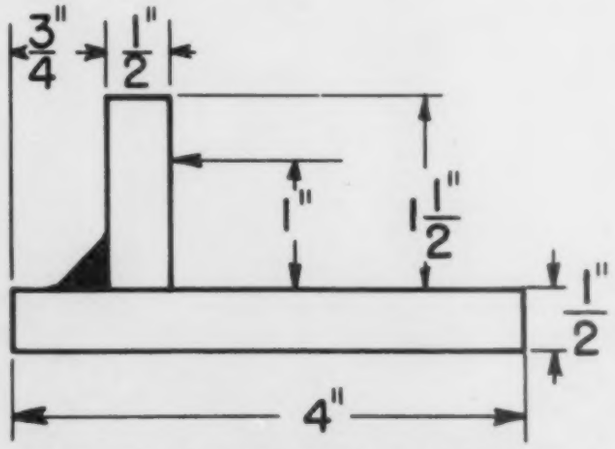

Fig. 1—A 1/2 inch x 1 1/2 inch Bar Is Welded to a 1/2 inch by 4 inch Bar with a 3/8 inch Fillet Weld. These Bars Are Usually 12 Inches Long, Thus Providing Several Specimens, as the Welded Assembly Is Cut into 1/2 Inch Strips

* Presented at a meeting of Fundamental Research Committee.
† General Electric Co.

Fig. 2—Fillet-Weld Specimen, in Special Attachment to American-Made Charpy Machine No. 14, Arranged for Transverse Impact Test

ness, because the resistance of the welds will be measured in foot-pounds, thus permitting quantitative comparison of welds produced by various processes.

A fractured weld is frequently desired for the purpose of determining the character of the weld metal by visual inspection. If such a specimen, generally called the "wedge test," is required, it might as well be made in the form shown in Fig. 1. so that the specimen can be tested in the Charpy impact testing machine and more information derived than is obtainable from the wedge test.

Figure 1 indicates the simplicity of the proposed specimen and test, and also shows that the impact load is applied 1 in. above the upper horizontal surface of the larger bar. A $^1/_2$-in. × $1^1/_2$-in. × 4-in. bar is welded to a $^1/_2$-in. × 4-in. × 4-in. bar, with a $^3/_8$-in. fillet weld. This assembly is then saw cut into $^1/_2$-in. strips. Three specimens only are needed for the average test and these can be taken from the central part of the assembly. The result is a group of inexpensive specimens from which considerable data can be obtained.

Figure 2 shows the proposed fillet weld specimen located in a special attachment to American made Charpy Machine No. 14 and ready for the impact test. The pendulum of the machine as it swings downward passes between the horns of the machine. The longer bar of the specimen is gripped firmly in the attachment while a cross bar is centered 1-in. above the longer bar and clamped to the shorter bar. The cross bar is so placed that it engages the horns of the machine, thus applying the impact load to the specimen. At the upper part of the machine is located the recording equipment which indicates the number of foot-pounds of energy required to fracture the specimen. It will be noted that the attachment and the general arrangement is such that the specimens can be tested very economically.

Figure 3 shows the proposed fillet weld impact test specimen arranged in the special attachment for the Charpy machine. The photograph shows a fractured specimen in the attachments thus illustrating the entire process. It will be observed that the attachments are of all-welded construction, indicating the advantages of welding in the fabrication of miscellaneous pieces of equipment. At the right end of the photograph is shown two fractured fillet weld specimens. The possibility of examining the fractures to determine penetration at the root of the weld and general character of weld metal is clearly shown.

Tests made to date indicate that the proposed specimen has considerable merit and that it achieves, to a high degree the objects sought for.

It is suggested that this test be given careful consideration and that suggestions for the improvement or modification of the test be sent to the writer. After such suggestions have been received, the proposed test will be modified and submitted for approval as a standard.

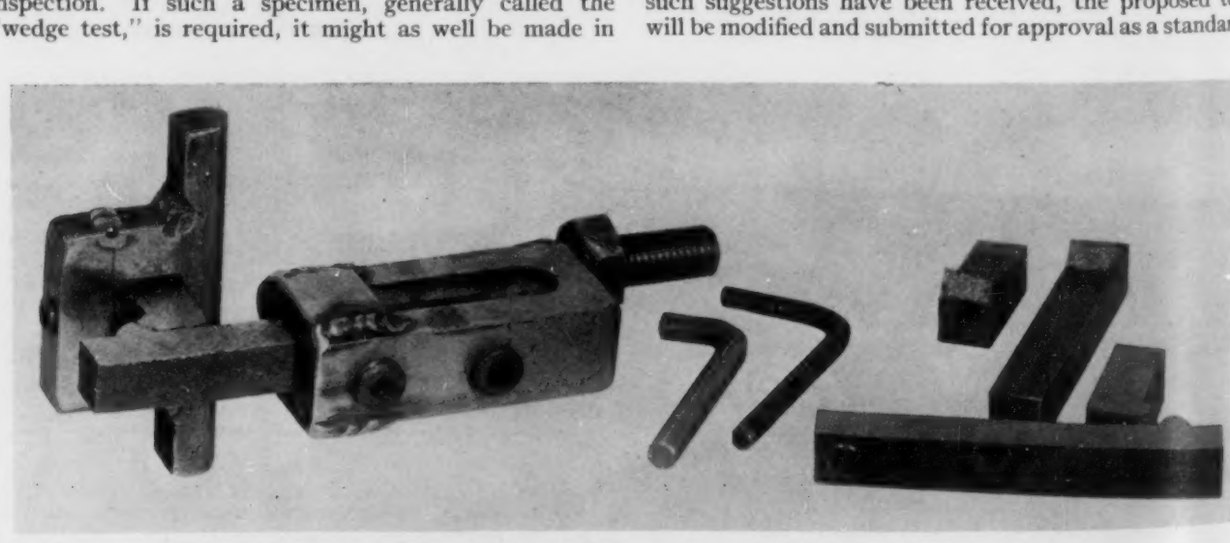

Fig. 3—Fillet-Weld Specimen, in Special Attachment for American-Made Charpy Machine No. 14, Arranged for Transverse Impact Test, and 2 Broken Fillet-Weld Specimens. Attachment Modified from That Shown in Fig. 2

Effect of Weld Penetration on Stresses in Fillet-Weld Joints*

By ARSHAG G. SOLAKIAN†

A VERY common and effective method of connecting the joints in structural members is by means of two lap plates symmetrically located on either side of the joint in the main plate. The connection is made solid by the action of fused weld metal in the form of fillets, applied either along the sides of the lap plates as in longitudinal weldings, or along the ends as in transverse weldings, or sometimes by the combination of the two types as in box welding, as illustrated in Fig. 1.

No satisfactory theoretical solution has been developed yet giving the exact stress distribution in the members of any of the common types of welded connections. Extensive mechcanical testing has been done mostly for the purpose of determining the ultimate strength of the joint as a whole, under various conditions of applied loading. Within the last few years only the photoelastic method of analyzing stress distributions by means of polarized light and transparent models has been applied to different phases of welded connections. A complete photoelastic solution has been offered by the author[1] for a 45°-fillet transverse weld, whose results have served as a basis of comparison by Gerbeau[2] with the theoretical solution developed by Goeltzer.[3] In this analysis the author also determined the comparative merits (in terms of stress concentration factors) for a great many modifications of the 45° type fillet weld, as shown in Fig. 2. It was found that a 30° x 60° fillet having the same volume of weld metal as the standard 45° fillet was the most effective, if the longest leg of the fillet was adopted as the shear area. Also it was found that a slight penetration of the weld metal into the slit formed between the lap and main plates was of the character to reduce the intensity of the hightest stress acting at the root of the slit. These facts were of sufficient importance to investigate thoroughly the nature and magnitude of stress effects

* Contribution to Fundamental Research Committee of Engineering Foundation and Bureau of Welding Research.
† Lecturer in Civil Engineering, Columbia University.

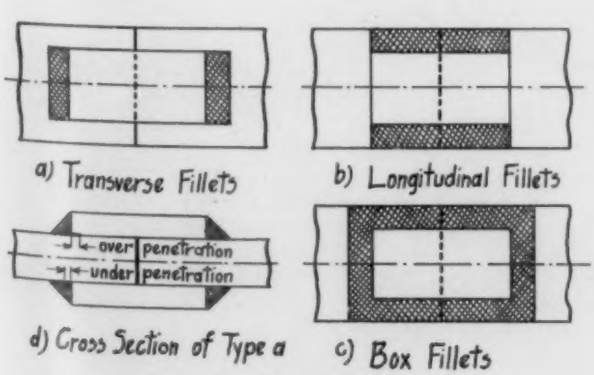

Fig. 1—Symmetrical Fillet Weld Joints

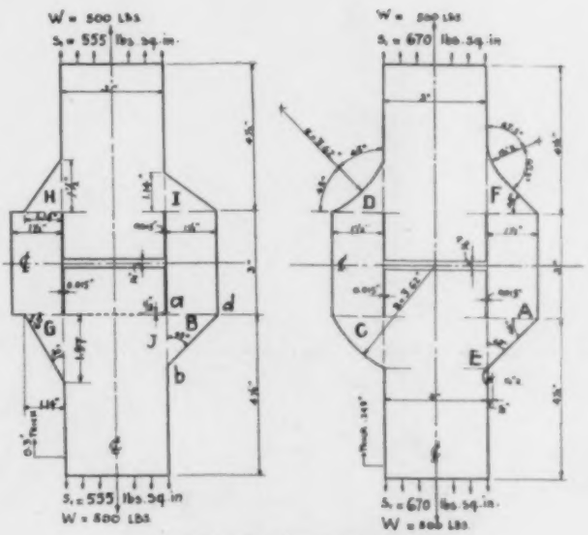

Fig. 2—Details of Transverse Weld Fillets

produced by changing the length of the two stressed areas (shear area $a-b$ and the tension area $a-d$), as a result of a variable penetration of the weld metal.

A photoelastic study of welded connections preassumes perfect homogeneity of material in the plates and the weld fillets. This as a matter of fact is never true in actual practice. However, for experimental purposes, disregarding this fact and by assuming also perfect fusion and uniform bond strength, then a model cut from a solid plate can be used for the investigation instead of a built-up model with cemented elements to represent the assemblage of the plates and the weld fillets. In the previous photoelastic investigation by the author it was found that the stress fringes were continuous across the cemented joints and were of an identical nature with those obtained from a solid plate model.

To determine the effects of over and underpenetration of weld, a model was prepared from a Bakelite (C25, water clear transparent) plate, same material as used in the previous investigation, having a fringe-stress value of about 86 lb. per sq. in. per inch thickness. The general shape of the model was the same as in Fig. 2 and the fillet studied was of type B in this figure, except certain details. The finished thickness of the plate in the model was 0.287 in. The thickness of the main plate (width of middle section) two in. and that of the lap plates one in. each. The width of the slit 0.015 in. The fillet investigated was the standard 45° type having one inch legs both for the shear and tension areas. Successive tests were made with the same model for various assumed penetrations of weld such as: $+^3/_8$, $+^5/_{16}$, $+^1/_8$, 0, $-^1/_8$ and $-^1/_4$ inch. After the results with the

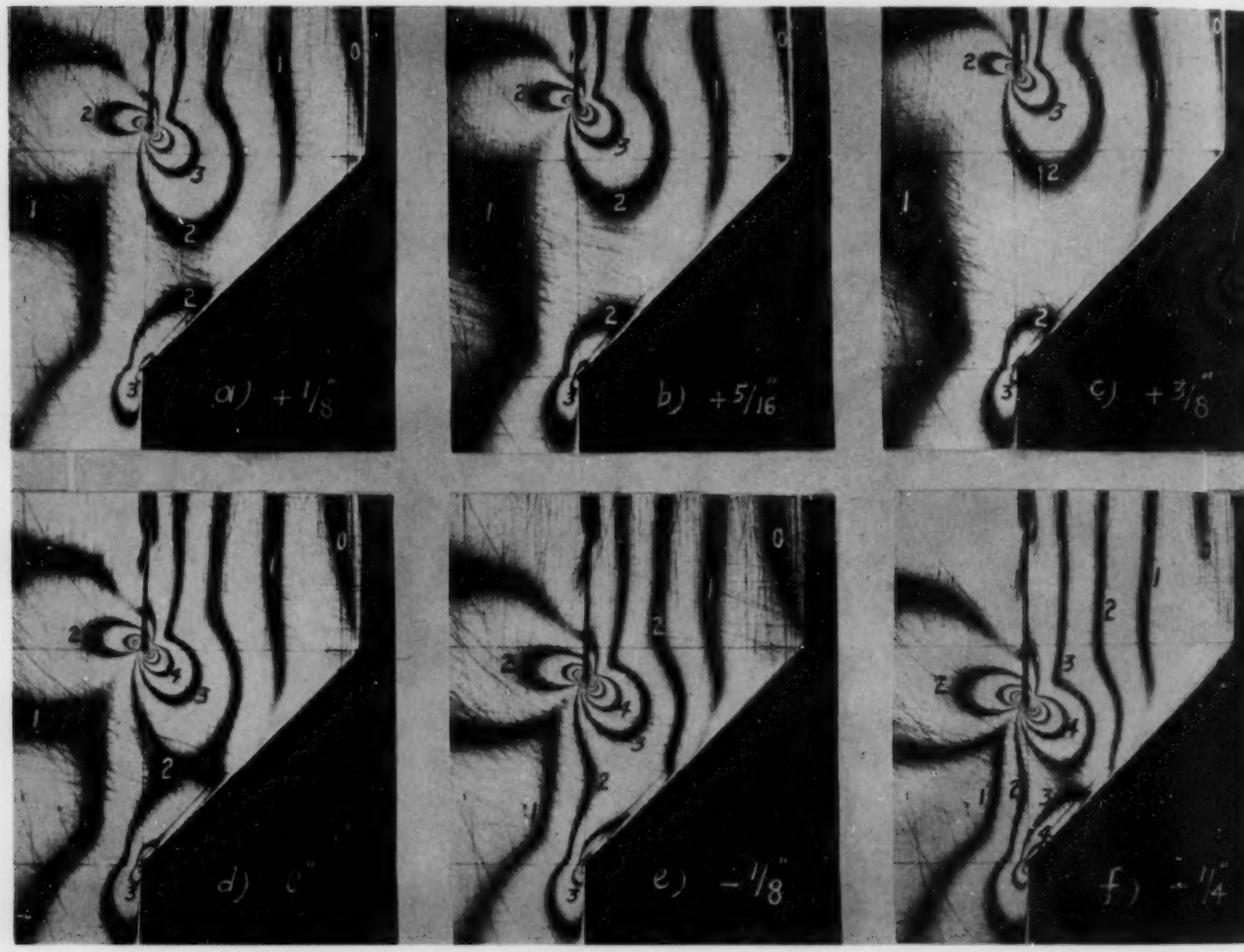

Fig. 3—Fringe Patterns Showing the Effect of Weld Penetration on Stress Distributions in Transverse Fillet Welds

$+^3/_8$ penetration test were obtained, the slit was lowered to the limit of the next value, namely the $+^5/_{16}$ in. penetration and so on until the lower limit of $-^1/_8$ in. was reached. By this way, all stress patterns were obtained from one fillet and thus errors due to variation of the stressed region under consideration were eliminated.

In each case a total load of 200 lb. was applied to the extremities of the model, producing a uniformly distributed average tensile stress of 348 lb. per sq. in. across the cross section of the model. The resulting fringe stress patterns obtained with circularly polarized monochromatic light (5461*A* line of mercury arc) are shown in Fig. 3. In these patterns each fringe line represents a constant value of $(\sigma_1-\sigma_2)$ stress, in intensity proportional to the order of the fringe, as marked on the photographs. As σ_1 and σ_2 are, respectively, the maximum and minimum principal stresses acting at a point in the plane of the model, and also one-half of their difference is known to be equal to the intensity of the maximum shear stress acting at that point, hence the distribution of this stress is obtained directly from the fringe patterns, and are shown graphically in Fig. 5 for the tension area $(a-d)$, and in Fig. 4 for the shear area $(a-b)$.

Forgetting for a moment the effect of change in the lengths of the stressed sections $(a-b)$ and $(a-d)$ on the intensities of the stresses acting over these sections, it is easy to observe from these sets of curves that the direct effect of an overpenetration is to reduce the intensities of the stresses at all points along the sections, and that of an underpenetration of an opposite nature, if comparison is made with the stress curve for the zero penetration of weld metal. In both cases it is found that the rate of decrease or increase of the stress is larger near the regions of the two critical points, namely the root (a) of the slit and the neck (b) of the fillet.

For a comparative study of the results obtained, Table 1 is prepared giving the values of the boundary stresses and the stress concentration factors (the ratio of the intensity of stress at point to the average stress in the model) for the two important points (a) and (b). These results are directly from the fringe stress patterns and the curves in Figs. 3 and 4. Since the various amounts of weld penetrations alter the lengths of the shear and tension areas in the model, the tabulated values in column 4

Table 1—Photoelastic Results for Various Weld Penetrations

1	2		3		4		5	
	Length of Stressed Area, Inches		Stress at Boundary Lb. per Sq. In.		Stress Concentration Factors		Revised Stress Concent. Factors	
Weld Penetration, Inches	Shear Area $(a-b)$	Tension Area $(a-d)$	Root Point (a)	Neck Point (b)	Root Point (a)	Neck Point (b)	Root Point (a)	Neck Point (b)
$+^3/_8$	1.375	1.000	1600	950	4.57	2.72	6.30	3.70
$+^5/_{16}$	1.312	1.000	1750	1020	5.00	2.92	6.55	3.85
$+^1/_8$	1.125	1.000	2000	1100	5.71	3.14	6.45	3.55
0	1.000	1.000	2350	1200	6.71	3.43	6.70	3.45
$-^1/_8$	0.875	0.875	2700	1340	7.71	3.83	6.75	3.35
$-^1/_4$	0.750	0.750	3080	1500	8.80	4.28	6.60	3.25
						Average	6.56	3.53

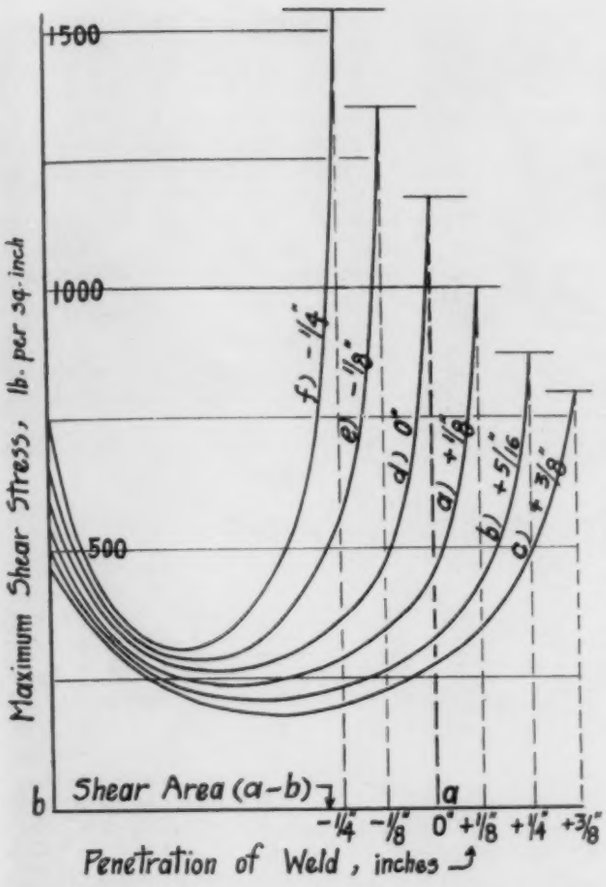

Fig. 4—Distribution of Maximum Shear Stress on Shear Area (a—b) for Various Weld Penetrations

are revised on the basis of a one inch length of stressed section, as in the zero in. penetration case. These revised values appear in column 5. In this connection, it should be mentioned, that the stress concentration factors largely depend upon the type of discontinuity of the boundary (size and shape of slit, notch, hole, etc.) more than the length of the stressed area, especially if the latter is comparatively large in relation to that of the over or underpenetration of weld metal. Since in this investigation the shape or size of slit is not changed, hence the resulting effects are due to change in length of the stressed areas. This is evident from the revised values of stress concentration factors (based on one inch length of area) in column 5, which all seem to be more or less constant, with a max. +2.9% and −4.0% variations (from the average) for point (*a*) and +9.1% and −7.9% variations for the point (*b*).

The relation between stress concentration factors with change in length of weld penetration is graphically shown in Fig. 6 for the two points under consideration. From these curves it is evident that for both points, the rate of increase in intensity of stress with the increasing of underpenetration of weld is linear. On the other hand, the intensity of the stresses are reduced by the increase in the amount of weld penetration, but at a gradually decreasing rate.

The injurious character of underpenetration of weld has been well investigated by mechanical tests, usually under static tension loading. Table 2 gives a résumé of some of the most important results.

There has been very little work done with welded connections under repeated or pulsating stress for the fatigue limit of the joint. Graf[9] has found that poor

Table 2—Results of Tests for Various Types of Welded Joints

Source of Information	Min. Strength in Terms of Average	Type of Fillet	Causes of Low Strength
Struct. Steel Research Report[4]			
Series 1000	68%	Trans. non-sym.	Insuff. penetr., partial fusion at root
Series 1900	75%	Trans. symmetr.	Incomplete fusion
Series 2000	30%	Trans. sym. with interrupted seam	Lack of fusion, poor penetr.
Series 2900–4300	80%	*V* and *X* butt welds	Poor penetr. at root of *V* or *X*
Bibber[5]	50%	Trans. sym.	Poor penetr. at root
Gillespie, Hughes, Jackson and Fox[6]	80%	.....	Defect. fusion at square angle of fillet
Kraus[7]	83%	Trans. sym.	.....
Raczkowski[8]	75%	Sym. double-T	Poor penetration

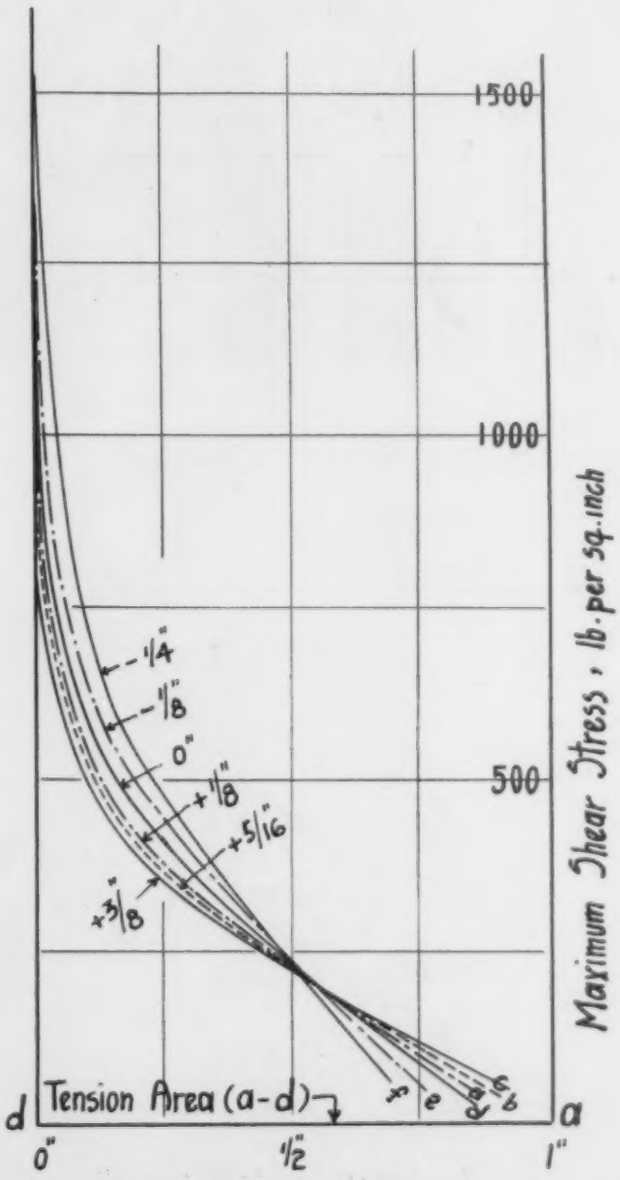

Fig. 5—Distribution of Maximum Shear Stress on Tension Area (a—b) for Various Weld Penetrations

penetration at the root of a double-*T* joint lowers the number of cycles of pulsating tension that the joint (bare electrode welds, mild steel plates) can withstand at an upper stress of +22,800 lb. per sq. in.; lower stress +11,400 lb. per sq. in. from greater than 6,300,000 (specimen with good penetration, not fractured) to 440,000–790,000 (poor penetration). End fillet welds are not quite so sensitive to poor root penetration; the end fillet joint with poor penetration having a pulsating tension fatigue limit of 17,800 lb. per sq. in., whereas the pulsating tension fatigue limit of the double-*T* joint was only 15,000 lb. per sq. in., with good penetration.

From the above Table 2 and the accompanying discussion it will be observed that no investigator has made the attempt to determine also the amount of underpenetration due to defective fusion, which could have been made easily by making a cross section of the fillet weld and examining under microscope. Consequently the photoelastic results obtained are not directly comparable with results from actual tests. Both methods definitely prove the injurious nature of underpenetration. The photoelastic study in addition, proves the beneficial nature of overpenetration as well as the magnitude of resulting effects in both cases. Tentative trials have shown that overpenetration of weld metal into the slit can actually be obtained by the proper manipulation of the welding apparatus, without any appreciable wasting of material or time. When one considers the fact that large stress concentration factors are specifically undesirable in structural members under dynamic or pulsating stress, than the necessity of reducing high localized stresses at the root of the slits in welded connections, by overpenetration of the weld metal, will be self evident.

The author is indebted to Mr. W. Spraragen, Secretary of the Welding Research Committee, The Engineering Foundation, for valuable data supplied in connection with actual tests of welded joints.

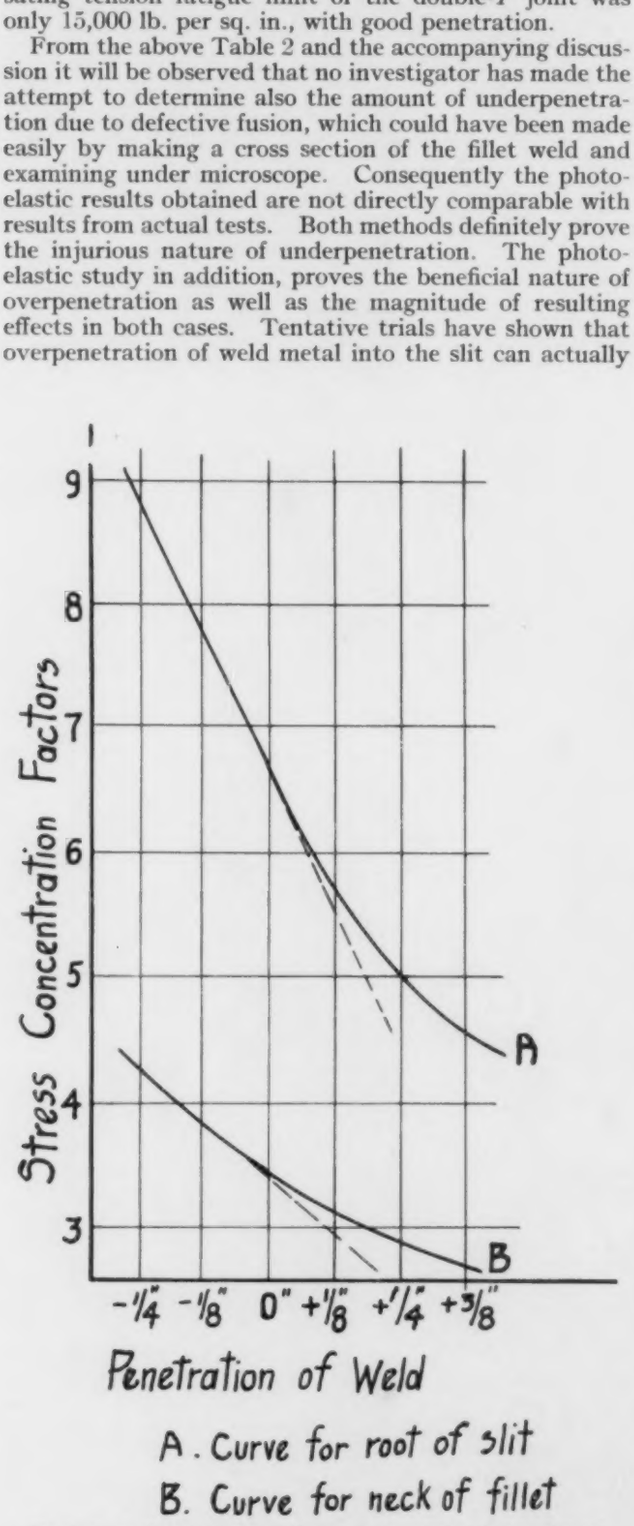

Fig. 6—Curves Showing Variation of Stress Intensity with Penetration of Weld

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Activities of German Research Committee

(*Continued from page 4*)

The forgeability test for welds given in DIN 1913, Specifications for Filler Metal, requires a weld to have Forgeability No. 4 in the Becker scale, with the slight difference that the DIN specimen is forged to one-half the original breadth and thickness whereas the Becker specimen is forged to one-half the thickness and two-thirds of the breadth.

The paper by Becker presents very important information on the numerical evaluation of the forgeability of welds.

Sub-subcommittee on Non-Destructive Testing

The group has in hand some work on the further development of X-ray inspection but insufficient progress has been made for a definite report.

Research Problems of Committee 3 on Methods of Testing

Problem 44: Tensile impact tests of welds are important at the present time in view of the proposed DVM standard (German Society for Materials Testing).

Problem 46: The Cooperative research on the bend test is completed. The results are embodied in DIN-DVM A121.

Problem 58: Free-Bend Test. The problem is being studied without charge at three laboratories. The apparatus constructed at the Committee's expense and used at the laboratories of the United Steelworks, Dortmund, is now being used in supplementary tests by Professor Matting at the Technical College, Hanover.

Problem 60: Fatigue Strength and Flame Cutting. The tests on oxy-cut low-alloy structural steel plate (St 52) with mill scale show:

The fatigue strength (pulsating tension) of specimens with oxy-cut surfaces is 34,100 p.s.i. Specimens with sawn surface gave 38,400 p.s.i. under the same conditions. Specimens with ground or milled oxy-cut surfaces gave intermediate values. Hence the effect of oxy-cutting is to lower the fatigue value of low-alloy structural steel about 10% (static tensile strength 74,000 p.s.i. minimum).

THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

Sponsored by American Welding Society and American Institute of Electrical Engineers

OCTOBER, 1936 No. 3

Welding Research

Ever since the organization of the American Welding Society, research has played an important part in its activities. The research work was conducted under the auspicies of an advisory board known as the American Bureau of Welding. This Bureau has been responsible for a modest number of very significant cooperative research projects in the welding field, notably the Welding of Structural Steel, Welding of Rail Joints and Welding of Pressure Vessels. The report of the Structural Steel Committee is the basis for the design of practically all welded steel structures at the present time, and the work of this Committee is still going on in connection with the study of strength and efficiency of various types of welded connections.

However, the most significant part of the work of the Bureau has been that carried out by its Fundamental Research Committee, which, with very little financial assistance, now comprises about sixty active research projects in many universities of the country from the East Coast to the West Coast, and even in Canada. Although some of these researches are obviously of minor importance they serve as a means of educating professors and students of the institution in question, thus providing a supply of young engineers who are familiar with welding. However, a considerable number of these researches have developed data, methods of analysis, and information as to the nature of the phenomena involved, which, all told, constitute a very major contribution to those industries concerned with welding. As a matter of fact, a considerable majority of the best papers presented before the AMERICAN WELDING SOCIETY are the results of these research projects.

As the Engineering Foundation Board had been appealed to on many occasions to give financial support to some of these projects, and as that Board was pretty generally conversant with the needs of Welding Research, it proposed the organization of a Welding Research Committee under the joint auspices of the AMERICAN WELDING SOCIETY and the American Institute of Electrical Engineers, for the purpose of coordinating the welding research work of the country under one comprehensive organization, and for the making and distributing of critical summaries of the world's literature on the subject. In order to get this work started, Engineering Foundation offered to prime the movement with a contribution of $5000 per year, providing a significant sum, sufficient to make the work worth while could be raised from industry.

At a luncheon meeting attended by some dozen executives personally known to members of the Committee something over $7000 was promptly pledged.

Although the organization of the Committee and its work is well started, it is by no means complete, as it is obvious that this will depend in some degree upon the budget which will, in turn, depend upon the funds available.

The Committee hopes to raise a minimum of $20,000 in addition to Engineering Foundation's contribution, as this will be necessary to provide a sufficient staff and office organization to carry on the work that has already been carefully planned for the three subcommittees which are as follows:

1. *The Literature Committee.*—Chairman, J. H. Critchett (Vice-President, Union Carbide and Carbon Research Laboratories). The purpose of this Committee is to prepare a critical digest of the World's Welding Literature and eventually to publish a series of books summarizing the best available knowledge in each part of the field. This series of books has its parallel in the Alloys of Iron Research Committee of the Engineering Foundation. Seven books have already been published and several more are in preparation. These books constitute the best existing summary of our knowledge of the Alloys of Iron, and the industrial corporations which are contributing to the project are more than satisfied with the results.

Although a considerable amount of work has been done by this Committee (in cooperation with the Fundamental Research Committee), funds available are altogether insufficient for the efficient conduct of the work in hand. It will be necessary to have a thoroughly competent editor, as well as a staff for translating and abstracting.

In the conduct of research investigations it is necessary that the investigator known what knowledge is already available. This information is also of value to the practicing engineer. Many thousands of dollars may be saved in preventing mistakes, or in duplicating costly investigations. One review recently completed in cooperation with the Fundamental Research Committee on "Fatigue of Welded Joints," involves a critical digest of more than four hundred articles appearing in many journals written in several languages. This critical digest represents more than a thousand dollars in time of trained workers having available adequate library facilities. It is estimated that this work alone would justify a considerable contribution on the part of any company interested in welding.

2. *Fundamental Research.*—Chairman H. M. Hobart (General Electric Company). As stated above, this Committee which is a carry-over from the American Bureau of Welding has much good work to its credit. Altogether more than 100 important reports have been issued.

There are several meritorious and important research projects already in hand which badly need some financial support, and it is the hope of the Main Committee that we shall be able to provide such support to the extent of $8000 or $10,000 per year.

In a number of instances these investigations have yielded the fundamental basic data on which important advances in the welding field have been made. A single contribution of this sort may be worth many times the entire cost of this cooperative research project.

3. *Industrial Research Committee.*—Chairman, Colonel G. F. Jenks (Commanding Officer, Watertown Arsenal). Although the organization of this Committee is not yet complete, it has an unusually fine start. Several Material subcommittees and several Functional subcommittees have already been organized and comprise some of the best talent of the country.

A two-day meeting of this Committee was held at the Watertown Arsenal in late July, there being approximately thirty-five persons present. In addition to the business session, a number of interesting papers were read and discussed, and the value of the Committee to all its workers and to the industry they represent, was cordially acknowledged by those present.

The purpose of this Committee is to coordinate industrial research without trespassing upon fields of a temporarily confidential nature. Statistics concerning researches either in progress or desired by industry have already been collected, and the work of the subcommittees is going forward. Colonel Jenks stated at the last meeting of the Main Committee that during the coming year no considerable financial assistance would be required by his committee, although it is quite possible that when the work is fully organized, a few important projects may be undertaken in cooperation, which might require considerable sums in addition to the services in kind provided by industrial corporations. This latter service is usually

(*Continued on page 15*)

The Effect of Low Temperature on the Tensile Impact Resistance of Iron, Steel and Welded Joints*

By OTTO H. HENRY†

WITH the fact in mind that there is a decided increase in the use of welding on most equipment, especially that of the aviation, refrigeration and railroad industries, which is normally subjected to low temperatures and that very little data on the tensile impact values of welded joints at low temperatures are to be found in the literature, the following data were compiled and evaluated.

Method of Making Tests

Since the necessary equipment was not available, a Tinius Olsen Impact Testing Machine of 100 foot-pound capacity was converted into a tensile impact testing machine with a capacity of 125.6 foot pound. The increased capacity was accomplished by adding cast babbit metal plates to the pendulum. To accommodate the tensile impact specimen a special jig was constructed which fitted into the place originally occupied by the steel jaw of the anvil of the machine. A close-up of the jig, specimen in place and cross-arm is shown in Fig. 1. The specimen, which is quite similar to a standard 2-inch tensile test specimen only proportionately smaller is shown in Fig. 2. When the pendulum is released it strikes the cross arm shown in Fig. 1 and thus applies a tensile impact load to the test piece. Before the pendulum is released the position of the cross-arm is adjusted so that it just touches the hammer when it (the hammer) has dropped to its lowest position, i. e., when the pendulum possesses the maximum kinetic energy. The striking side of the cross-arm is formed to fit the curved side of the hammer.

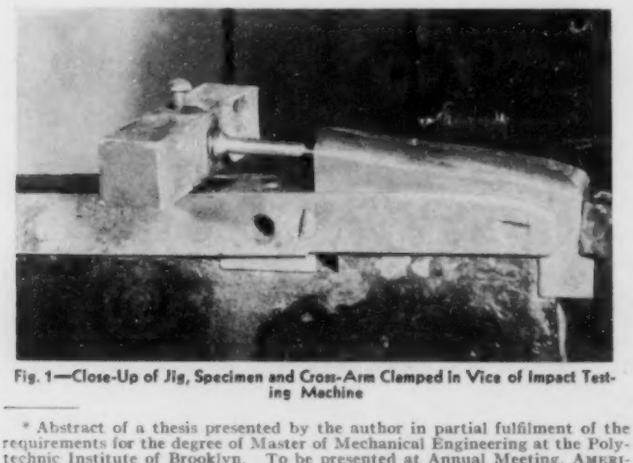

Fig. 1—Close-Up of Jig, Specimen and Cross-Arm Clamped in Vice of Impact Testing Machine

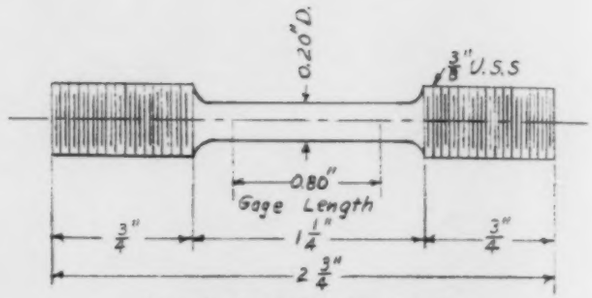

Fig. 2—Tensile Impact Specimen Twice Size

Temperature Control

An ether bath cooled by solid carbon dioxide (dry ice) was first used and then it was found more advantageous, due to the rapid evaporation of the ether, to use absolute alcohol with a small percentage of ether. The jig with the specimen and cross-arm in place were immersed in the bath until cooled to the proper temperature when the whole assembly was quickly transferred to the testing machine and the specimen ruptured.

In order to make the transfer from the bath to the testing machine as rapid as possible the jig was attached to the ends of two thin metal strips, the other ends of which were made to turn about a pivot on the base of the machine, Fig. 3. It was not necessary to touch the jig or specimen in any way while the transfer from the bath to the testing machine was being made. The jig and assembly were simply swung about the pivot from the bath to the vise of the machine. The jig with a specimen in place in the cooling chamber is shown diagrammatically in Fig. 3.

The container for the cooling medium is a copper tank placed inside of a larger wooden box. The 4-inch space between the copper tank and the box is filled with hairfelt for insulation.

Before making a test, alcohol and ether were poured into the copper tank to a depth which would cover the jig and the specimen. Dry ice was then added through the hole in the cover until a temperature, about that desired, was indicated by the thermocouple. The lid was then removed and the jig, with the specimen in place, was lowered into the bath. The cover was then replaced and dry ice was slowly added until the potentiometer indicated that the specimen had reached the desired temperature. The desired temperature was easily main-

* Abstract of a thesis presented by the author in partial fulfilment of the requirements for the degree of Master of Mechanical Engineering at the Polytechnic Institute of Brooklyn. To be presented at Annual Meeting, AMERICAN WELDING SOCIETY, Oct. 1936. A Contribution to the Fundamental Research Committee of Engineering Foundation and the AMERICAN WELDING SOCIETY.

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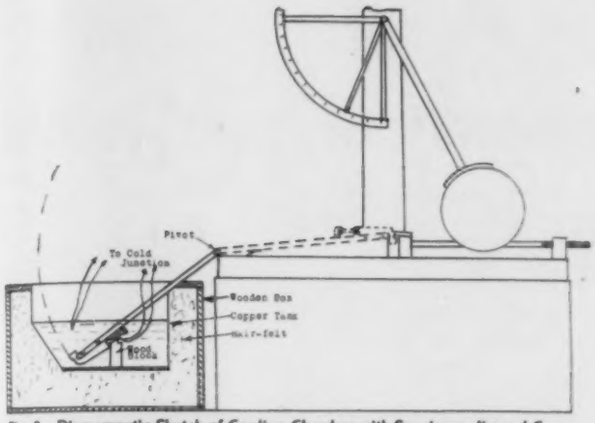

Fig. 3—Diagrammatic Sketch of Cooling Chamber with Specimen, Jig and Cross-Arm Immersed in Cooling Bath

tained due to the method of construction and insulation of the tank.

The specimen was held at the desired temperature for at least fifteen minutes and then the cover was quickly removed and the jig swung into position in the machine, the vise tightened and the pendulum released. No difficulty was experienced in removing the specimen from the bath and rupturing it in slightly less than two seconds.

Some experiments were made by E. A. Imbembo[42] to determine the change in temperature (if any) of the specimen while being transferred from the cooling bath to the machine. He found after several trials that in the time it takes to make a test (about 2 seconds) there was no change in the temperature of the specimen. Another interesting thing was that the temperature of the specimen started to drop after about four seconds and at the end of 7 or 8 seconds reached a temperature of 3 or 4 degrees Centigrade less than its original temperature. After this temporary fall the temperature began to rise but it took fully fifteen seconds before it reached its original temperature of −80° C. This drop in temperature is in all probability due to the rapid evaporation of the thin layer of ether remaining on the specimen and jig after removal from the bath.

Temperature Measurements

Two thermocouples made with 22 gage copper and 20 gage constantan wire were connected through a zero degree Centigrade cold junction to a Leeds and Northrup portable potentiometer. One thermocouple was used to measure the temperature of the bath while the other was placed in contact with the center of the reduced section of the specimen as shown in Fig. 3, which is a section of the cooling chamber. Before rupturing a specimen it was made certain that both thermocouples indicated the same temperature.

The thermocouple locations are shown in Fig. 3. The cold junctions were inserted in glass tubes in which some mercury had been placed. These four glass tubes were passed through the holes of a rubber stopper which fitted the top of a thermos bottle containing a mixture of cracked ice and water In this particular case the so-called cold junction is a misnomer because it is at a higher temperature than the so-called hot junction.

Materials Tested

Tensile Impact tests were made on:

(1) Plate metal samples, seven in number, in order to check the results obtained by Mr. Imbembo, who had sufficient specimens for one test only at several temperatures.
(2) Seventeen high strength bronze welds, supplied by the Union Carbide and Carbon Research Laboratories.
(3) Eleven Electric Resistance welds, supplied by the Union Carbide and Carbon Research Laboratories.
(4) Twelve Naval Bronze welds, supplied by Air Reduction Sales Company and tested by Mr. E. A. Imbembo, under direction of the author.
(5) Nine Atomic Hydrogen welds supplied by the General Electric Company and tested by Mr. E. A. Imbembo under direction of the author.
(6) Fourteen specimens of Armco Ingot Iron.
(7) Twenty-two samples of 0.85% Carbon steel.
(8) Twelve 18–8 stainless steel samples supplied by the Allegheny Steel Co.
(9) Fourteen 18–8 stainless steel Gas Welded, Unannealed, specimens supplied by the Allegheny Steel Co.
(10) Fifteen 18–8 stainless steel Arc Welded, Unannealed, specimens supplied by the Allegheny Steel Co.

The material used for the carbon steel plate metal and the electric resistance and high strength bronze welds was of the following composition:

Carbon	0.25%
Manganese	0.57%
Sulphur	0.022%
Phosphorus	0.016%

The plates were $^3/_8$-inch thick and the procedure was to make the welds in plates that were 6 inches x 15 inches. The plates were beveled at 45 degrees along the 15-inch dimension. Therefore, after being welded the plates measured 12 inches x 15 inches with the weld at right angles to the direction of rolling in the steel. Strips $^3/_8$-inch wide normal to the axis of the weld were then cut by means of a power hack saw. After these strips had been cut to the required length with the weld in the center the tensile inspect specimens were machined from them.

This general procedure was followed for both the high strength bronze and the electric resistance welds. The Armco Ingot Iron and the steel specimens were made from $^3/_8$-inch hot rolled rod and tested in the unheat-treated condition. The composition of the high-strength welding rod was as follows.

Copper	58.00%
Zinc	39.85%
Tin	1.00%
Iron	1.00%
Silicon	0.10%
Manganese	0.05%

There is no definite information as to the composition of this metal after welding, according to the Union Carbide and Carbon Research Laboratories, but it is quite likely that there is some loss of silicon and zinc.

The material for the stainless steel specimens was supplied by the Allegheny Steel Co. and they were cut from a $^5/_8$-inch plate which had the following composition:

C	0.075%
Cr	19.72%
Ni	8.86%

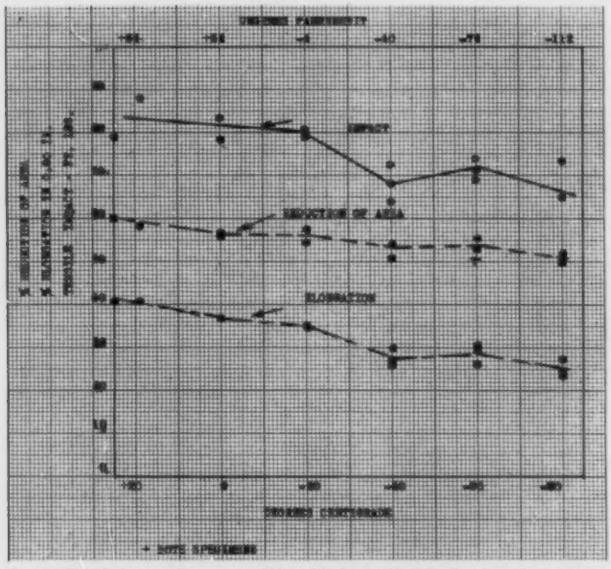

Fig. 4—Tensile Impact Properties of Unwelded 0.25% C Steel at Low Temperatures

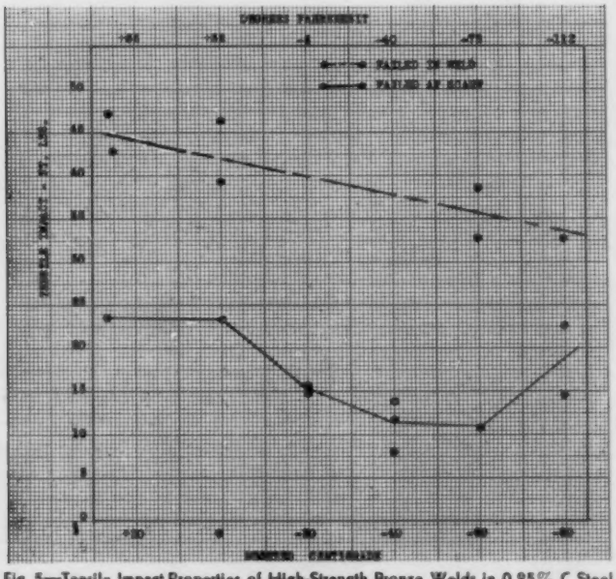

Fig. 5—Tensile Impact Properties of High-Strength Bronze Welds in 0.25% C Steel at Low Temperatures

The analysis of the welding rods used in both the electric and gas welds was:

C	0.083%
Cr	19.72%
Ni	8.91%

In all cases the weld is of the "V" type and is located in the center of the specimen.

Results of Tests

The experimental results obtained from the tensile impact tests are plotted in curve form in Figs. 4 to 17.

Conclusions

I. Relating to the Tensile Impact Values of Welds

(*a*) Mild Steel

Table of Average Values of Rupture Energy and Ductility in Tensile Impact of Welded Plates at +20 and −80° C.

Welding Method	Energy of Rupture Ft.-Lb.		Elongation % in 0.8 In.		Reduction of Area %	
	+20	−80	+20	−80	+20	−80
Plate Metal (Not Welded)	83	66	41	25	59	51
Electric Butt Welds	61	52	25	18	54	51
Atomic Hydrogen	55	40	35	21	71	66
Naval Bronze Brazed	28	22	18	16	33	29
High Strength Brazed	45	33	25	18	50	50*

* Results of the brazed joints (high-strength bronze) that failed in the scarf are not included in these averages.

The table shows that the electric butt and atomic hydrogen processes produce welds in mild steel having

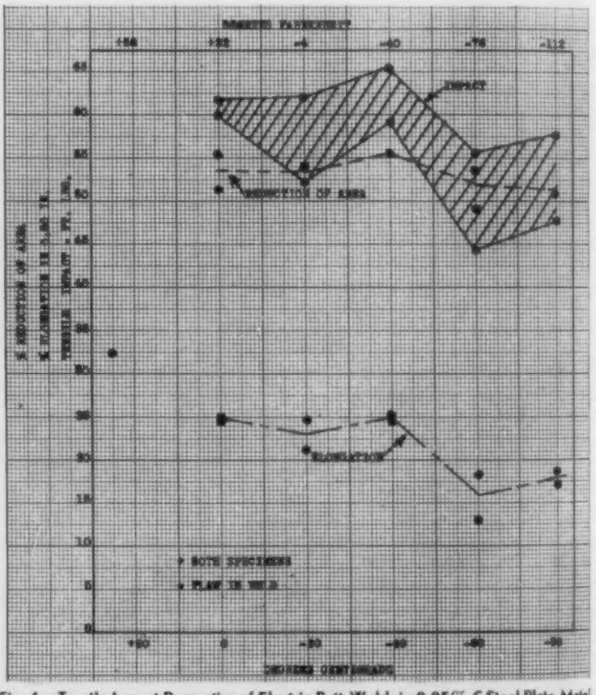

Fig. 6—Tensile Impact Properties of Electric Butt-Welds in 0.25% C Steel Plate Metal at Low Temperatures

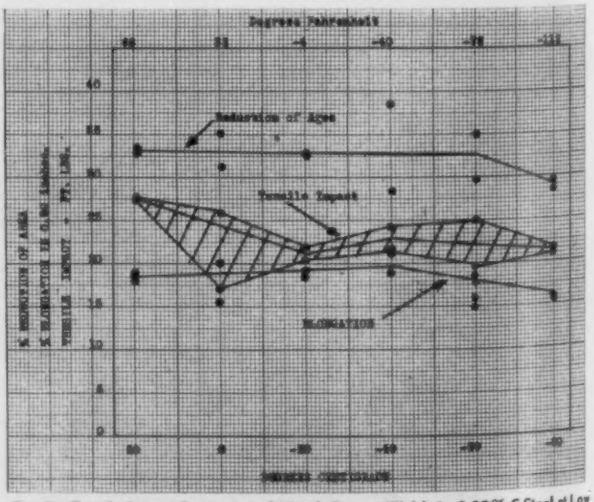

Fig. 7—Tensile Impact Properties of Naval Bronze Welds in 0.25% C Steel at Low Temperatures. (By Emil A. Imbembo—under the author's direction)

about the same tensile impact value. The electric butt welds have somewhat better rupture energies but lower ductility at 0 to −20° C. and at −80° C. than atomic hydrogen welds. At intermediate temperatures (−20 to −40° C.) the elongation of the electric butt welds is equal to that of the atomic hydrogen welds. The good impact value of the latter agree with the high Izod values of atomic hydrogen welds determined by C. H. Davy (Instn. Chem. Eng. Oct. 1935). The spread was about twice as much in the atomic hydrogen as in the butt welds. The temperature impact curve of the butt welds resembled that of the parent metal to a greater extent than the atomic hydrogen welds. The rupture energy and ductility of the butt welds rose to a maximum of 63 ft.-lb., 55% red. of area, and 25% elongation at −40° C. and then dropped abruptly to 50 ft.-lb. 16 and 53%

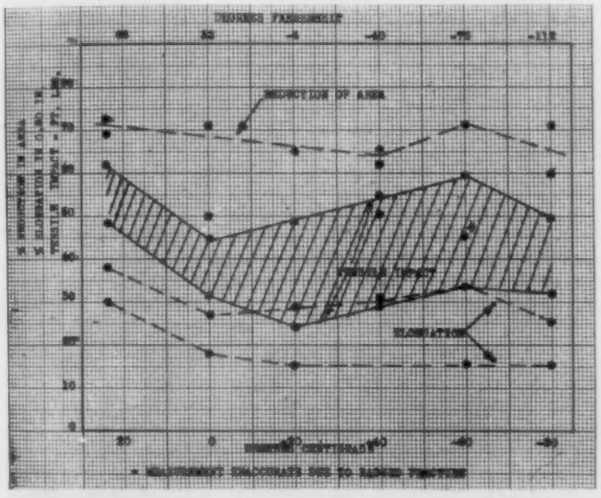

Fig. 8—Tensile Impact Properties of Atomic Hydrogen Welds in 0.25% C Steel at Low Temperatures. (By Emil A. Imbembo—under the author's direction)

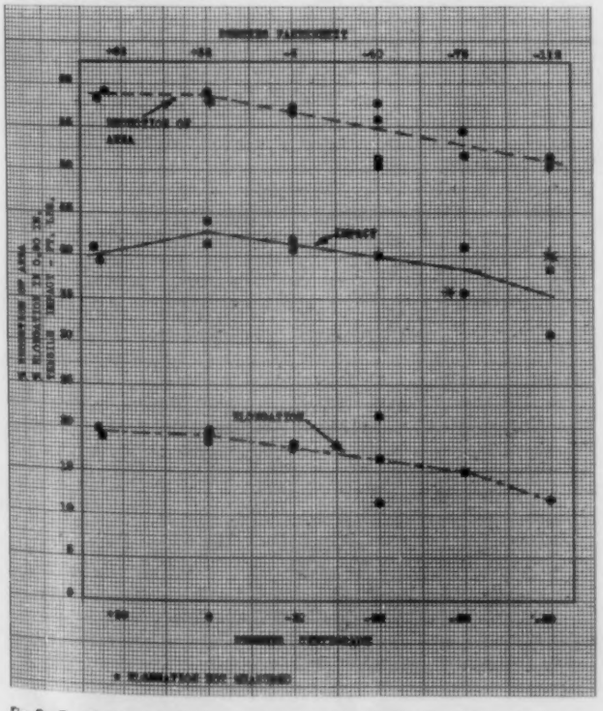

Fig. 9—Tensile Impact Properties of Unwelded Armco Ingot Iron at Low Temperatures

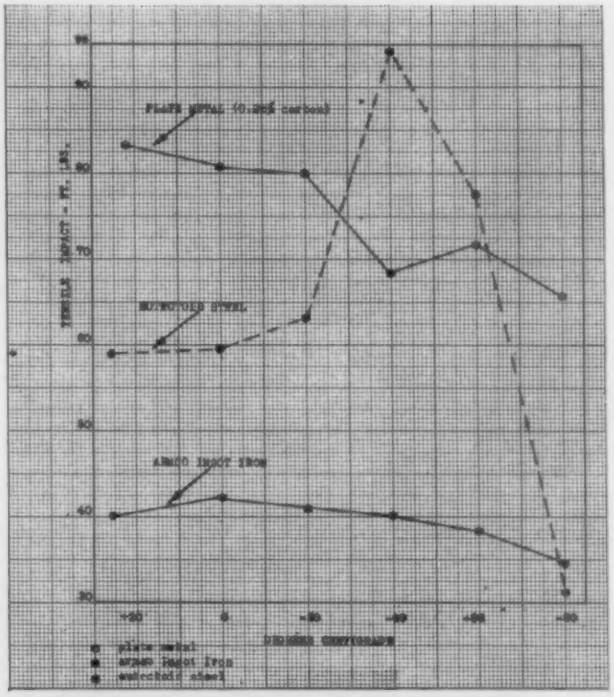

Fig. 10—Combined Graph of Tensile Impact Value of Unwelded Armco Ingot Iron, 0.25% Carbon Steel and Eutectoid Steel at Low Temperatures

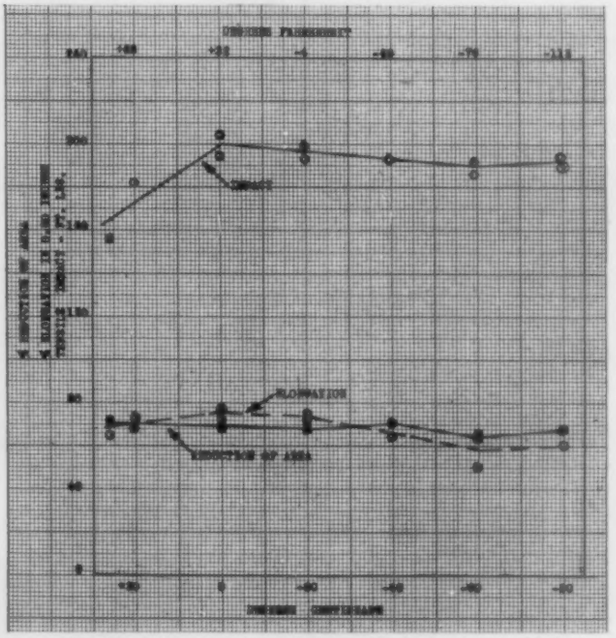

Fig. 11—Tensile Impact Properties of Unwelded 18-8 Stainless Steel Plate Metal at Low Temperatures

respectively at −60° C. The brazed joints were 25 to 50% lower in rupture energy than the welds. It appeared that (with good workmanship), it would be advantageous to use high-strength bronze welds. The spread in the naval bronze was surprisingly low (30% maximum). It was thought that the tensile impact value of the brazed joints would rise with decrease in temperature in view of the well known beneficial effect of low temperature on the physical properties of copper and brass. This, however, was not found to be true.

Both welded and brazed joints were inferior to plate

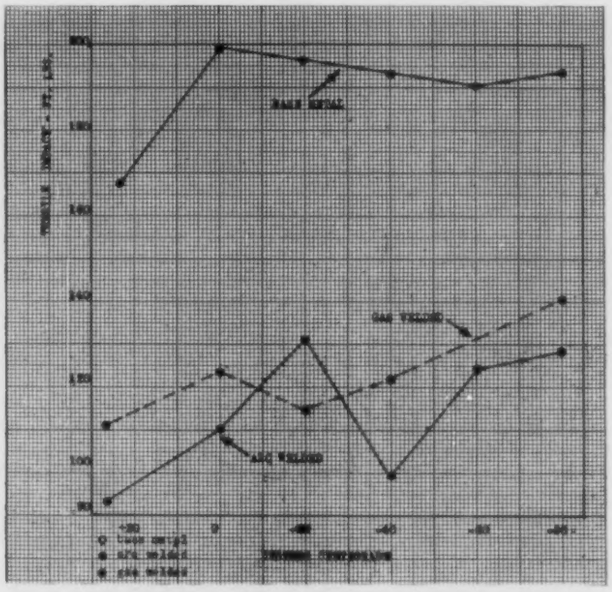

Fig. 12—Combined Graph of Tensile Impact Values of 18-8 Stainless Steel as Received, Arc Welded Unannealed and Gas Welded Unannealed at Low Temperatures

metal in rupture and with the exception of the atomic hydrogen welds, in ductility also.

(*b*) Stainless Steel (18–8)

Table of Average Values of Rupture Energy and Ductility in Tensile Impact. 18–8 and Unannealed Welds Therein at +20 and −80° C.

Material	Energy of Rupture, Ft.-Lb.		Elongation % in 0.80 In.		Reduction of Area, %	
	+20	−80	+20	−80	+20	−80
Plate Unwelded	160	195	70	62	70	68
Gas Welded	110	140	46	39	68	23
Arc Welded	95	130	37	35	50	35

The spread was large for both the arc and gas welding processes, Figs. 12 and 13. The peculiar weakness of gas welds at −60° C., verified on four specimens must be borne in mind as well as the fact that one gas welded specimen gave 152 ft.-lb. at −20° C. and one arc welded specimen at −20° C. gave 170 ft.-lb. with excellent ductility. All in all the results show that gas and arc welds in 18–8 with good workmanship are only 27 and 13% inferior, respectively, to plate metal in tensile impact.

The fact must be kept in mind that all specimens were tested in the unannealed (as welded) condition. It is quite likely that the results would have been very much different if the samples had been heat-treated after welding.

II. Correlation of Tensile Impact results with other Physical Properties.

(*a*) There appears to be no correlation between the curves of rupture energy *vs.* temperature as determined by the notch impact test and the tensile impact test. The characteristic feature of rupture energy *vs.* temperature curves for notch impact tests of mild steel welded or unwelded, is the transition zone, usually located at +20 to −20° C. In the range of temperatures constituting this transition zone, the notch impact value (Izod, Charpy or Mesnager) drops from room temperature value of about 30 ft.-lb., to practically zero. There is no corresponding pronounced transition zone in the respective energy *vs.* temperature curves for tensile impact tests, if the relatively small effect at −40° C. is neglected. The tensile impact results show, therefore, that the transition zone is a peculiarity of the notch and the stress distribution associated with it. This is confirmed by Lohmann,[34] who showed that the unnotched Charpy specimens of welds often showed no transition zone, at least down to −80° C.

(*b*) It also appears that there is no correlation between the curves of energy (or stress) to rupture *vs.* temperature as determined by the static tension test and the tensile impact test. Figure 9, for unwelded Armco ingot iron, shows a slight increase in tensile impact energy from +20 to 0° C. and then a constant decrease to −80° C. Unwelded low carbon steel shows similar behavior, Fig. 4, except that the decrease in tensile impact energy is most marked between −20 and −40° C. Below −40° C. there is little further decrease to −80° C.

The results of static tensile tests on the same unwelded steel, Fig. 16, show a steady increase in tensile strength as the temperature decreases from +20 to −80° C. Figure 16 also shows that the increase in tensile strength is accompanied by a slight but regular increase in ductility as measured by percentage elongation.

The decrease in tensile impact value as the temperature is lowered is accompanied by a decrease in ductility, as shown in Fig. 4. The relation between strength and ductility in both the static (slow speed) tensile test and the tensile impact test as the temperature is lowered is opposite to the usual conception that, other things being equal, an increase in tensile strength is achieved at the expense of ductility, and vice versa.

(*c*) The conclusions of the preceding section may be more closely considered on the basis of total resilience. As the temperature is lowered the static tensile results indicate that the total resilience, a function of the product of tensile strength and ductility or deformation to rupture, increases consistently because both tensile

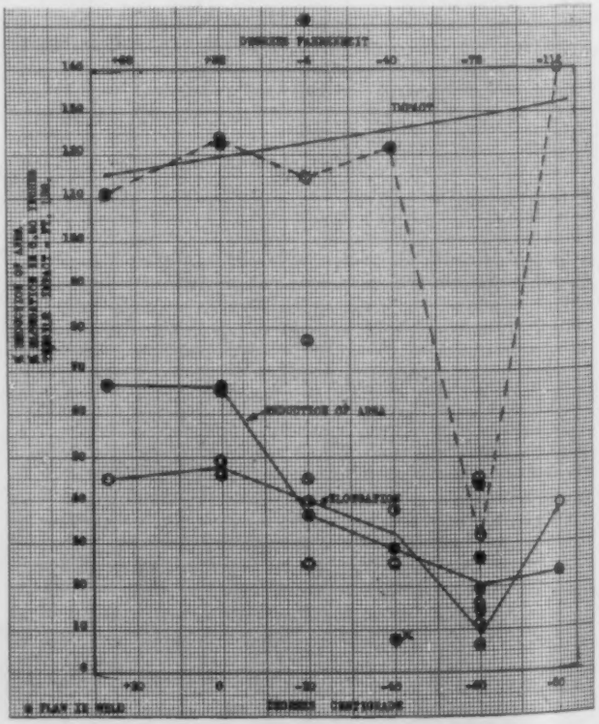

Fig. 13—Tensile Impact Properties of 18-8 Stainless Steel Gas Welded Unannealed at Low Temperatures

strength and elongation increase. The tensile impact energy, however, decreases considerably as the temperature decreases. Since the tensile impact energy of rupture is in reality a function of the total resilience (tensile strength × deformation), it is clear that the change of total resilience in unwelded mild steel with decrease in temperature varies with the rate of application of load. With a slow rate of application (static test) the resilience increases with fall of temperature; with a high rate of application (tensile impact test) resilience decreases with fall of temperature. The present tests thus indicate that the rate of change of total resilience (rupture energy) in tension with temperature undergoes a reversal of sign between the speed of application of load in the static tensile test (about 0.001 ft./sec.) and the speed in the tensile impact test (about 14 ft./sec.).

(*d*) The question immediately arises: Is the decrease in rupture energy of mild steel in the tensile impact tests as the temperature is lowered due to a decrease in strength or to a decrease in deformability (ductility)? Figure 4 shows that elongation in the tensile impact test decreases from 40% at 20° C. to 25% at −80° C., a decrease of 38%. This decrease is proportionately larger than the decrease in tensile impact rupture energy, which falls from 80 ft.-lb. at 20° C. to 70 ft.-lb. at −80° C., a decrease of only 13%. It may therefore be deduced that the decrease of rupture energy in the tensile impact tests is due to a decrease of deformability of the mild steel rather than to a decrease of stress resisting properties. It should be remembered that the static tensile tests indicated an increase of both ductility and strength as the temperature is lowered.

(*e*) The reasoning applied in the preceding paragraph indicates than an actual increase in stress resisting properties may be expected in the tensile impact tests of mild steel as the temperature is lowered. If this be true, then the rate of charge of deformability with temperature is much higher at high testing speeds than at the low speeds employed in the usual static tension tests. The conclusion of section (*c*) should be borne in mind in this connection. This conclusion may now be stated in two parts: (1) The rate of change of deformability (ductility) in tension with temperature undergoes a reversal of sign between the speed of application of load in the static tensile test and the speed of application in the tensile impact test; (2) the rate of change of strength in tension with temperature probably does not undergo a reversal of sign between the speeds in question.

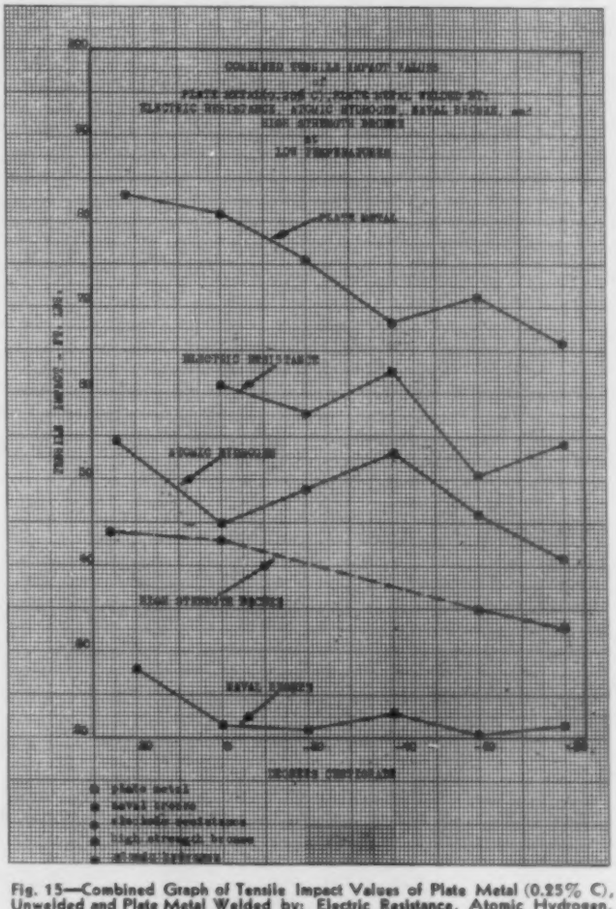

Fig. 15—Combined Graph of Tensile Impact Values of Plate Metal (0.25% C), Unwelded and Plate Metal Welded by: Electric Resistance, Atomic Hydrogen, Naval Bronze and High Strength Bronze at Low Temperatures

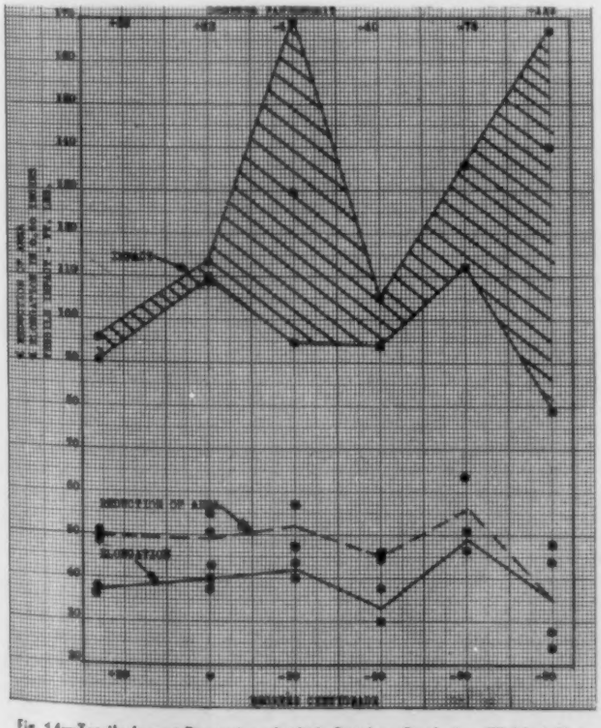

Fig. 14—Tensile Impact Properties of 18-8 Stainless Steel Arc Welded Unannealed at Low Temperatures

(*f*) These two conclusions may perhaps be related to a strain-aging phenomenon which occurs at all temperatures from 20 to −80° C. The more rapid the application of stress the more adverse is the effect of the hypothetical precipitate on ductility. An explanation similar to this has recently been proposed by Davenport and Bain, based on Körber's static tensile results, to account for changes in total resilience and deformability of low carbon steel in the temperature range 20 to 500° C. The results of the present tests indicate that the increase of ductility in tension as the temperature is lowered may be larger at rates lower than 0.001 ft./sec. than in the usual static tensile tests.

(*g*) The tensile impact properties of normalized eutectoid steel, Fig. 17, are entirely different from mild steel and Armco ingot iron. Between +20 and −20° C., in eutectoid steel, there is a slight rise of rupture energy of several ft.-lb. There is a 70% increase, however, between −20 and −40° C. which is unaccompanied by any significant change in ductility. Between −60 and −80° C. there is an abrupt drop of rupture energy to 30 ft.-lb., with negligible ductility. It is not surprising that the eutectoid steel possesses a different rupture—

temperature relationship than mild steel in view of the fundamentally different microstructure and reaction to aging effects of the two types of steel. Perhaps tensile impact tests over a wide range of speeds at +20 to −80° C., using the machine devised by H. C. Mann, Watertown Arsenal, will shed light on the unexpected impact properties of eutectoid steel.

(*h*) The results for unwelded stainless steel (18–8) show that high-tensile impact values are retained even at −80° C. The results from 0 to −80° C. are 30 ft.-lb. higher than at room temperature. The ductility values are slightly lowered (5%) as the temperature is lowered from +20 to −80° C.

(*i*) In the unwelded materials there were considerable differences in the spread of rupture energy at any testing temperature as shown in the following table:

Material	Maximum Percentage Spread
Armco Ingot Iron (Hot Rolled)	25%
Mild Steel (Hot Rolled)	15%
Eutectoid Steel (Normalized)	up to 100%
18–8 (as Rec'd)	5%

The spread in ductility values was proportional to that in rupture energy.

(*j*)

Table of Average Values of Rupture Energy and Ductility in Tensile Impact of Unwelded Plates at +20 and −80° C.

Material	Energy of Rupture, Ft.-Lb.		Elongation % in 8 In.		Reduction of Area, %	
	+20	−80	+20	−80	+20	−80
Armco Ingot Iron	40	35	19	12	58	51
Mild Steel	83	66	41	25	60	51
Eutectoid Steel	60	30	13	3	20	0
18–8	160	195	70	62	70	68

The above table when considered together with the static tensile strength, Fig. 16, shows that energy of rupture in tensile impact is not proportional to tensile strength and that ductility values vary in a way that is scarcely accountable at present. In considering the table, the large increase in rupture energy of eutectoid steel to nearly 100 ft.-lb. at −40° C. should be borne in mind.

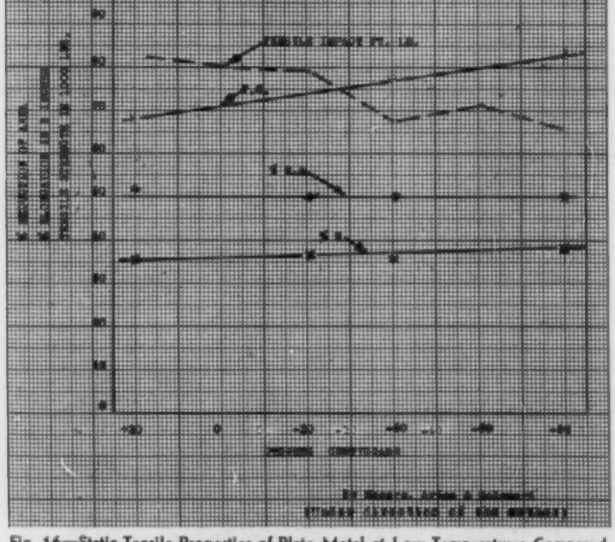

Fig. 16—Static Tensile Properties of Plate Metal at Low Temperatures Compared to Tensile Impact Values

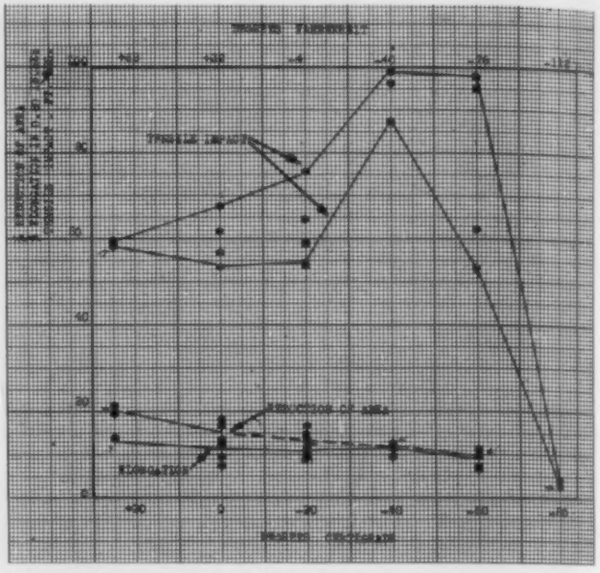

Fig. 17—Tensile Impact Properties of Eutectoid (0.85% C) Steel at Low Temperatures

Acknowledgments

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Welded Structural Brackets*

By CYRIL D. JENSEN†

Introduction

IN MANY structures of steel there are found small but important connecting links known as brackets. In buildings these brackets almost invariably support *I*-beams which in turn carry considerable loads. Practically no literature was found on the subject of Bracket Design except a theoretical study by Malcom Priest.** This study by Priest has been very sensibly made and it is the writer's hope that the investigation presented herewith will reinforce Priest's paper to such an extent that structural engineers will accept welded brackets with confidence.

Brackets may be divided into two groups (Fig. 1): (1) The flexible type of which the seat angle is the principal, and (2) the rigid type of which there are many designs. The rigid type of bracket generally consists of two plates, a top plate and a web plate, as shown in Fig. 1*B*, or it may be a short section of an *I* or *H* section as shown in Fig. 1*C*. Variation in the shapes of the brackets are indicated by the dotted lines "*a*" and "*b*" in sketches *B* and *C*. The flexible type of bracket (seat angles) will not be discussed in this paper since it has recently been investigated under the direction of the Structural Committee of the AMERICAN WELDING SOCIETY.‡

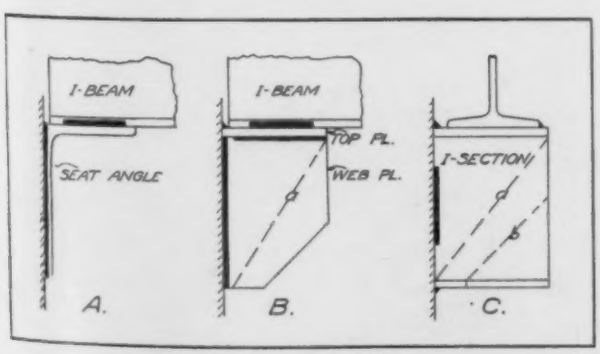

Fig. 1—Seat Angle and Brackets

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† Fritz Engineering Laboratory, Lehigh University.
‡ "An Investigation of Welded Seat Angles" by Inge Lyse and Norman G. Schreiner, A. W. S. JOURNAL, February 1935.
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Scope of the Investigation

The investigation was carried out in three steps:

1. The testing of eight celluloid models by polarized light, for the purpose of determining the lines of stress in the web plate with results as shown in Fig. 2.
2. The testing of two brackets of steel, Fig. 3, which were built to a linear scale of seven times the celluloid models, the purpose being to check the models and to measure more precisely the stresses in the webs.
3. The testing of twenty-two small brackets (Fig. 4 and sketches in Table 1) built for the most part of $^3/_8$-inch plates for the purpose of determining the reserve strength of the bracket webs and to determine the accuracy of a proposed method for designing the welds.

Results

A. Celluloid Models.—As will be noted in Fig. 2, each specimen consisted of two celluloid brackets placed back to back. The usual procedure was followed of first sketching in the boundaries of the colors (shown on the left half of each specimen) thereby obtaining lines of equal difference of stress between the two principal stresses. Since the diagonal edge of each web plate (Fig. 2, *A* and *B*) is a free boundary there exist on that edge only one principal stress and the colors along that edge therefore show directly the intensity of stress. These stresses have been plotted as ordinates normal to the edge of the plate. For the remaining specimens, *C* to *H*, difficulty was encountered since the color bands did not extend out to the free boundaries. On the other hand the absence of color bands on the free boundaries showed low stresses at those sections indicating an excess of material. Specimens *D*, *E* and *F* are modifications of *E* in an attempt to improve the appearance of the bracket, and increase the efficiency of the material without sacrificing load carrying ability. The next step was to obtain the isoclinics (*loci of points of equal orientation of principal stresses*) from which the stress trajectories were drawn. These latter are shown on the right half of each specimen.

In Specimen *A*, Fig. 2, several features should be noted. (1) The color chart on the left shows that the

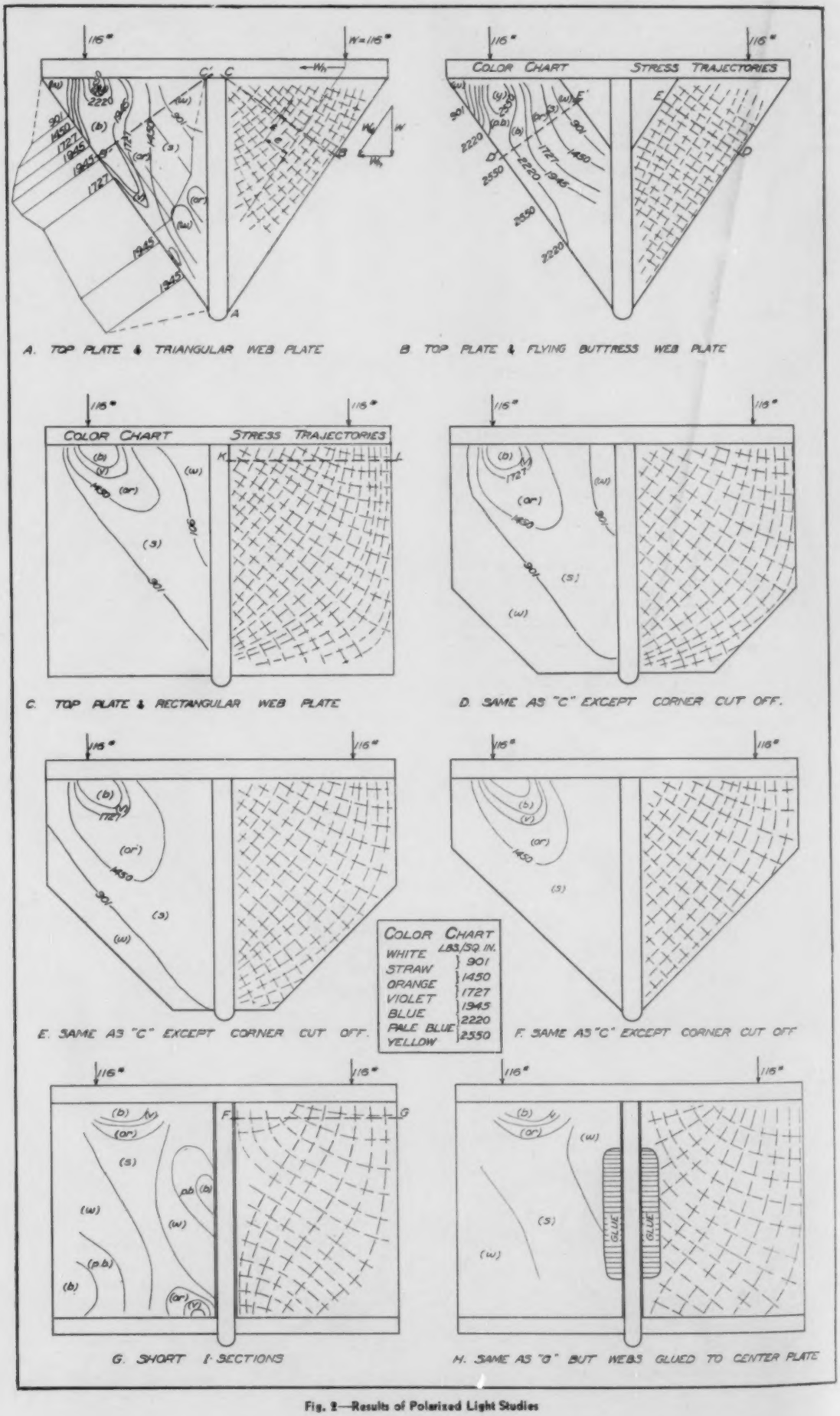

A. TOP PLATE & TRIANGULAR WEB PLATE
B. TOP PLATE & FLYING BUTTRESS WEB PLATE
COLOR CHART
STRESS TRAJECTORIES
C. TOP PLATE & RECTANGULAR WEB PLATE
D. SAME AS "C" EXCEPT CORNER CUT OFF.
E. SAME AS "C" EXCEPT CORNER CUT OFF.
F. SAME AS "C" EXCEPT CORNER CUT OFF
COLOR CHART
LBS./SQ. IN.
WHITE 901
STRAW 1450
ORANGE 1727
VIOLET 1945
BLUE 2220
PALE BLUE 2550
YELLOW
G. SHORT I-SECTIONS
H. SAME AS "G" BUT WEBS GLUED TO CENTER PLATE
GLUE

Fig. 2—Results of Polarized Light Studies

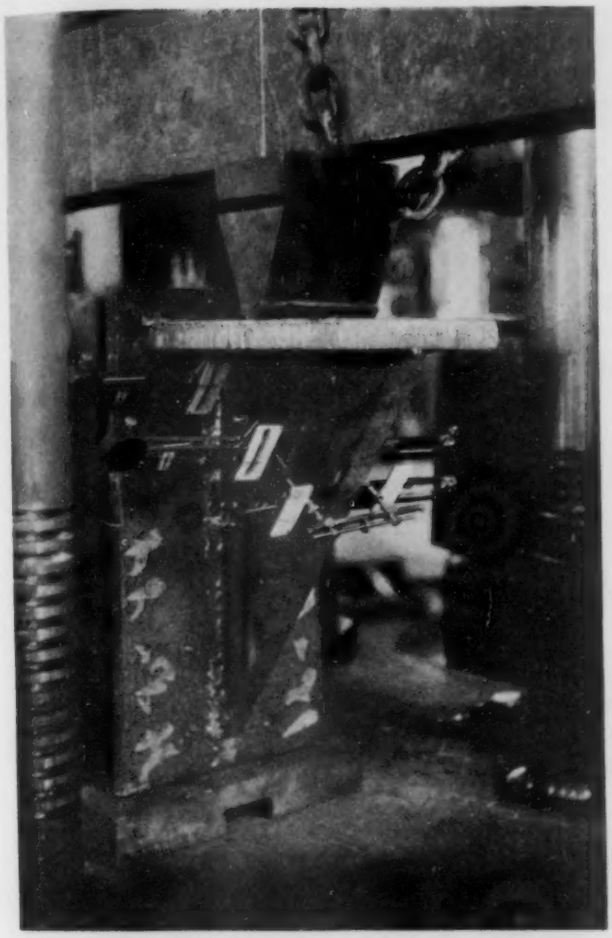


Fig. 3—Huggenberger Tensometers on Prototype

stress, very small on the inside corner of the web plate, increases in intensity toward the free edge. (2) The stress trajectories along the section BC are all nearly normal to the section from which it seems reasonable to assume that at any point along BC there is only one principal stress or rather that the principal stress in the direction BC is small. Tentatively, therefore, we can plot stresses along $B'C'$ without the usual elaborate analysis, but withhold judgment as to the reliability of this assumption until a check is obtained in the steel prototype. The stress variation along sections $B'C'$ and $D'E'$, decreasing so markedly from outside edge inward suggested the possibility of using the design formula for eccentric loads on prisms,

$$f = \frac{W_d}{A} \pm \frac{M}{S} \qquad (1)$$

where f = stress at B, C, D or E in pounds per square inch

W_d = component of the applied load, normal to the section being studied (see Fig. 2A)

A = area of section = $t(BC)$ or $t(DE)$

M = bending moment due to eccentricity of load = $W_d e$ (see Fig. 2A)

S = section modulus = $\frac{t(BC)^2}{6}$ or $\frac{t(DE)^2}{6}$

where t is thickness of web plate in inches. The resulting computed stresses have been plotted on prototypes A and B, Fig. 5, where can also be seen the agreement with the measured stresses.

Specimen B, Fig. 2 shows the results of omitting that portion of the web plate which receives but little stress. It will be noted that the stress trajectories are exactly as expected and there appears little doubt but what the usual formula for combining an axial load with a bending moment will yield good results.

Specimens C–E, Fig. 2, can be grouped under one discussion. It is rather evident from a study of the trajectories in Specimen C that section KL is critical and that specimens D, E and F will probably carry the same load as C.

Specimens G and H, Fig. 2, represent brackets consisting of short sections of I-beam. Two methods of welding have been suggested, (1) Top and bottom welds as simulated by Specimen G, and (2) top and bottom welds plus a web weld to carry the shear as shown in Specimen H. The color bands on the left half of Specimen G indicate a poor stress distribution at the lower point of contact. It is evident that a better distribution of stress obtains for Specimen H than for G.

B. Steel Prototypes.—The stress trajectories obtained for the celluloid models indicated that in the steel prototypes the principal stresses in each web plate could be measured along the indicated sections by setting the Huggenberger tensometers parallel to the diagonal edge of the plate. This was done with results as shown in Fig. 5A. The stresses have been plotted normal to sections BC and DE. Note that the stresses from the celluloid model, increased by the proper amount according to the laws governing model analysis, agree rather well with the stresses actually found in the prototype. But of more importance is the agreement between the actual stresses in the steel brackets and those computed by the method just suggested.

The steel prototypes were retested (Fig. 5B) with an attempt made to so place the loads that uniform stresses would obtain in the web plates. Due to lack of knowledge of just where the applied load changed direction and began down the incline supposedly parallel to the diagonal edge, it was impossible to place the loads definitely. The moment arms selected were based on the assumption that the load line would extend vertically through the top plates as shown in Fig. 5B and then suddenly change to the diagonal. This theory was not entirely borne out by the actual measured stresses, leading to the conclusion that the resultant force is not quite parallel to the diagonal edge of the web plate but is inclined more steeply downward as suggested by the lines to F and G in Fig. 5B.

That the resultant force in the web plate takes a direction slightly more vertical than the diagonal edge of the plate is substantiated by two points not mentioned heretofore:

(1) Abnormal strains in the region between G and the outer edge of the web plate (see Fig. 4) and,

(2) Point of computed resultant compressive stress in the welds using the method suggested by Priest, is in the region of F and G, Fig. 5B.

Up to this point attention has been focused on the web plate because it proved amenable to the polarized light studies. From these studies, verified by the tests on the prototypes, and from our knowledge of mechanics the following points may be made: (1) A large bending moment exists which puts the critical parts of the bracket web in compression and the top plate in tension; (2) the shearing load on the bracket is, in the main, carried by the web plate; (3) the line of action of the compression in the triangular-shaped web plate is roughly parallel to the diagonal edge of the plate; and that the stresses in the web plate may be approximately com-

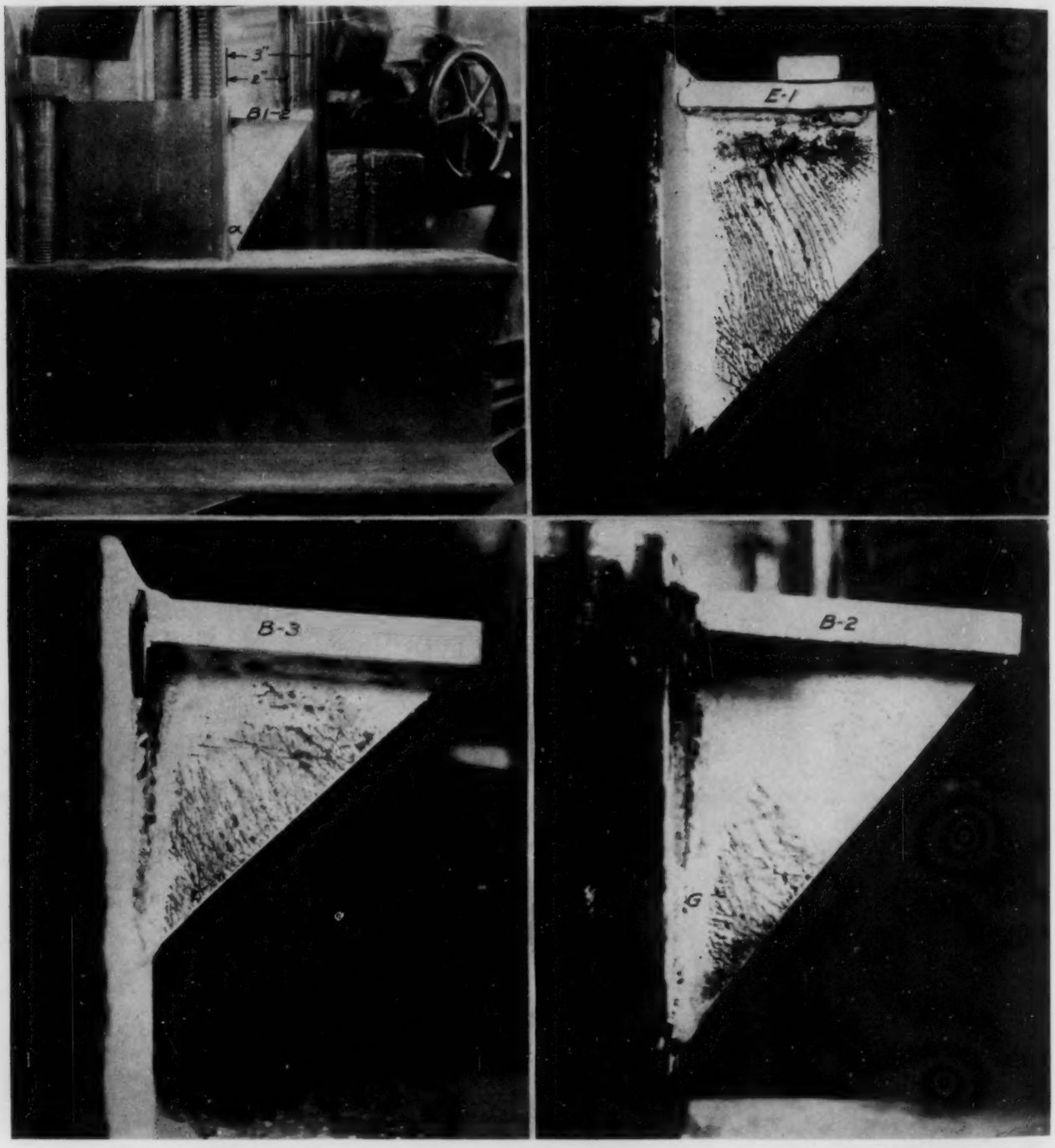


Fig. 4—Small Bracket Tests

puted from the formula $f = \frac{W_d}{A} \pm \frac{M}{S}$. The probability is good that the webs with the rectangular profile including those with the 45° cut on the lower corners may be designed with the same formula but with the work simplified because the critical section in each case is perpendicular to the applied load. There remains to show the tests to destruction indicating the toughness of the brackets and showing the types of fracture obtained and to outline a proposed method for designing the brackets.

C. Small Steel Brackets, Series B.—For the tests to failure, sixteen small steel brackets were constructed of $^3/_8$-inch plates, two brackets with $^1/_8$-inch web plates; and four larger brackets were made (Fig. 6), two of which had $1^1/_4$-inch web plates and the other two of which were 8-inch *I*-sections. Figure 4 shows a number of the small specimens. The key dimensions are shown in Table 1.

In all of the small brackets the top plates were two inches wide by three inches long and the load was applied two inches from the face of the column. It should be noted that *B* 1–2 is like *B*–1 except for the length of the top weld. A similar comparison may be made between specimens *B* 2–2 and *B*–2 and between *B* 3–2 and *B*–3. Specimens *B*–1, *B*–2 and *B*–3 differ in vertical length of web plate as indicated by angle α. The *C* group are like the correspondingly numbered speci-

Table 1—Results of Tests

Specimen Number	Thickness of Web Pl.	Size of Top Weld	Angle or Length L	Sketch	First Appearance of Strain Lines on the Whitewash	Strain Lines Thruout Web Plate	Ultimate Load	Predicted Ult. Loads Based on: 40,000 lb/sq.in. in Web	Predicted Ult. Loads Based on: Weld Strength	10,000 lb/sq in. in web	Weld Strength 2000 lb per 1/4" Fillet Weld	General Strain First Appearance	Factors of Safety: Web Plate Ult. (8)(11)	Factors of Safety: Web Plate Yield Points (7)(11)	Factors of Safety: Web Plate Yield Points (6)(11)	Factors of Safety: Weld (8)(12)
B1	3/8	1/4x1.1"	30°		21,000	28,000	30,000	23,000	38,400	9,310	8,640	1.33	3.22	3.01	2.25	3.47
B1-2	"	1/4x2	"		20,000	32,770	38,500	"	50,000	9,310	11,220	1.63	4.14	3.52	2.15	3.42
B2	"	1/4x1.2	36°50		14,000	20,000	23,800	20,900	36,300	7,490	5,910	1.43	3.18	2.67	1.87	4.02
B2-2	"	1/4x2	"		16,400	26,100	33,040	"	35,600	7,490	8,000	1.59	4.41	3.49	2.19	4.14
B3	"	1/4x1.25	45°		13,000	21,670	24,300	19,600	18,000	6,300	4,040	1.80	3.86	3.45	1.91	6.02
B3-2	"	1/4x2	"		18,700	25,000	26,700	"	35,300	6,300	5,690	1.33	4.24	3.97	2.96	4.69
C1-2	"	"	30°		24,100	28,800	42,100	23,000	50,000	9,310	11,220	1.19	4.52	3.10	2.59	3.75
"	"	"	"		25,000	28,700	40,600	"	"	9,310	11,220	1.12	4.36	3.08	2.75	3.62
C2-2	"	"	36°50		22,200	26,500	30,980	20,900	35,600	7,490	8,000	1.19	4.13	3.54	2.96	3.87
"	"	"	"		27,700	29,300	35,800	"	"	7,490	8,000	1.06	4.78	3.91	3.70	4.48
C3-2	"	"	45°		19,000	21,700	25,070	19,600	25,300	6,300	5,690	1.14	3.88	3.44	3.01	4.41
"	"	"	"		18,600	21,200	22,300	"	"	6,300	5,690	1.14	3.54	3.37	2.95	3.92
D1	1/8	"	30°		6,700	8,000	8,800	7,680	----	3,110	---	1.19	2.83	2.57	2.15	--
D2	"	"	5.2"		8,500	9,200	9,400	9,000	----	3,380	---	1.08	2.78	2.72	2.51	--
E1	3/8	"	5.2"	*	16,150[1]	40,000	50,000[2]	27,000	50,000	10,100	11,220	2.42	4.95	3.96	1.60	4.45
E2	"	3/8x2	5.2"	*	33,300	39,500	54,600	"	66,700	10,100	15,000	1.18	5.41	3.90	3.28	--
E3a	1.25	3/8x3.5	8.6"	1*	110,000	129,000	150,000	89,000	213,000	32,100	40,000	1.13	4.69	3.90	3.44	3.75
E3b	1.25	1/2x3[2*]	10.0"	1*	60,000	75,000	166,000	89,000	213,000	32,100	40,000	1.25	5.81	2.34	1.87	4.65
B4-2	3/8"	1/4x2	36°50		24,230	29,380	32,440	19,200	26,300	8,620	5,920	1.21	3.77	3.47	2.80	5.50
B5-2	"	"	30°		28,440	31,700	37,370	22,600	33,300	10,160	7,490	1.12	3.68	3.13	2.80	5.00
F1	1/2	3/8x4.25	8"I-Beam, see Fig.		32,400	57,300	120,000	68,000	157,000	25,300	26,100	1.77	4.74	2.26	1.28	4.70
F2	"	5/8x4.25			50,000	62,000	128,000	"	"	25,300	29,400	1.24	5.06	2.45	1.98	4.36

* 2.0"testing arm
1* 3.2" " "
2* Weld on under side of top plate

1 - Early strain lines due possibly to internal welding stresses
2 - Limit of machine,- specimen near ultimate load

mens of the *B* group except that the web plates were not in contact with the column. It was thought that the *B* group specimens may have been unusually strong due to the contact but it will be noted that there is very little difference in the ultimate loads. Specimen *E*–1, like *B* 1–2 and *C* 1–2 as regards welding details, shows the effect of the shape of plate on the ultimate load. A study of columns 8, 9 and 10 leads one to believe that the relatively weak webs of *B* 1–2, *C* 1–2, *E* 3*a* and *E* 3*b* had a considerable influence on the ultimate loads taken by the welds. Specimens *D*–1 and *D*–2 were made of $^1/_8$-inch web plates to insure a buckling of the web. As will be noted, the computed stresses in the webs at the buckling loads were slightly above 40,000 lbs. per sq. in. Specimen *B* 4–2, was made similar to *B* 2–2, except for the inner portion of web which is missing in *B* 4–2. In this same manner *B* 5–2 may be compared to *B* 1–2. The ultimate loads in both comparisons are in agreement within three per cent, indicating that, if desired, the inner portion of the web may be safely omitted.

Four rather large size specimens were tested, *E* 3*a*, *E* 3*b*, *F*–1 and *F*–2, as a final check on certain design formulas which are presented in this paper. As noted in Table 1, the web plates of *E* 3*a* and *E* 3*b* are $1^1/_4$ in. thick; the top plates are 4 by $1^1/_4$ by $4^1/_4$ inches and the load was placed (as suggested by Priest) at the 0.8 point or 3.2 inches from the face of the column. The writer was impressed by the toughness of these brackets and it will be noted in columns 14–17, Table 1, that good substantial factors of safety were obtained.

Concerning the suggestions to use short lengths of *I*-sections for brackets, the design methods appeared so elementary that but two specimens, *F*–1 and *F*–2, were made and tested. The results, see Table 1, show ample reserve strength and lead to the conclusion that, if other conditions permit, the short *I*-sections may be selected with assurance and with ease of computation. Load-deflection readings were taken on these two specimens with rather interesting results. As noted in Fig. 8 the welding of the web of specimen *F*–1 to the column made it definitely stiffer than specimen *F*–2. Specimen *F*–2 carried 6.7 per cent more load than *F*–1 in spite of the excessive deflection which took place. From the standpoint of economy of welding there is little to choose between the two: *F*–2 with its two $^5/_8$-inch welds is about as costly to make as is *F*–1 with its $^3/_8$-inch welds on the flanges plus ten inches of weld on the web.

Design

The proposed method for designing the welds has already been stated in an excellent paper by Mr. Priest in the August 1933 JOURNAL of the AMERICAN WELDING SOCIETY, but will be briefly restated here as a matter of record. Treat the fillet welds as if they were single lines and find the center of gravity axis, *x*–*x* (Fig. 7). Since tearing of the top weld is feared, find the shearing and bending stresses there as indicated by letters *V* and *H*. The example given in the figure should make the application clear.

Mr. Priest placed his top welds on the under side of the top plate in order to avoid harmful contact between beam and weld. The writer realizes the strength of this argument, but, since it is easy to avoid this contact, has included a chart covering welds at the top of the top plate. The reason is that the welds at the top of the plate are so much stronger than those at the bottom

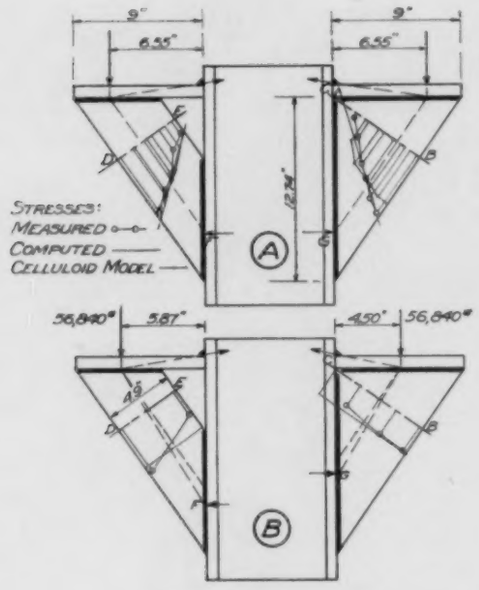


Fig. 5—Stresses in Steel Prototypes

(tension instead of shear—see the writer's report in the February 1934 JOURNAL of the AMERICAN WELDING SOCIETY) that the top welds should be used whenever possible. In any case the chart in this paper should be considered as an addition to Mr. Priest's chart since the same method has been used in designing the welds. The writer has added a formula for obtaining the thickness of web plate, a point in the design which is missing in Priest's report. Thus, for designing brackets either similar in shape to that pictured in Fig. 7 or with the web plates triangular in profile as in Fig. 2*A* the charts, Priest's or the writer's depending on whether the top welds are on the under or upper side of the top plates, may be used. However, the designer must be content with the specified ratio of length of top weld to vertical welds or make up a new set of curves.

The dimensions of the web plate are established for each individual case using a reasoning somewhat as follows: The width "*d*" of web plate is established first. If the *I*-beam rests on the bracket as in Fig. 1*B*, that is, with the webs of the two in the same plane, the distance, *d* (Fig. 7) is determined from the formula (see any up-to-date steel handbook) for end crippling of beams. If the *I*-beam rests on the bracket as in Fig. 1*C*, that is, with the web of the *I*-beam perpendicular to the web of the bracket, the distance "*d*" would naturally be such that the bracket projects out past the lower flange of the *I*-beam by at least a half inch to provide for welding space. The remaining steps in the design are given in the example in Fig. 7, provided the web is of the general shape shown. In case the web is triangular in profile the formula for thickness, $f = \frac{W}{A} + \frac{M}{S}$ must be modified as explained in the results of the celluloid model tests.

The designer should be alert for unusual bracket designs where some other sections of the web than *BC* in Fig. 2*A*, *DE* in Fig. 2*B*, *KL* in Fig. 2*C*, and *FG* in Fig. 2*G* are critical. For example, in specimens *B*–3 and *B* 3–2 (Table 1) where the triangular-shaped web plates were short in the vertical dimension (45° web plate) a section such as *CA* in Fig. 2*A* was stressed, according to computations, to about the same extent as the section *BC*. For another example, if the web plate in Fig. 2*B* is reduced in width, *DE*, but made thick the problem of adequate welds of this plate to both the top plate and column becomes important. For the usual case there is no problem of determining size of welds between top and web plates unless the designer is bent on specifying the smallest possible welds in which case the computations are quite simple.

Agreement between Design and Tests

Columns 9 to 17 have been added to Table 1, to show the relationships between design and the test results. If the method for determining web stresses is satisfactory, columns 7 and 9 should show agreement, since in computing the loads it was assumed that the yield point had been reached and that a rectangular distribution of stress obtained. Actually the computed values are lower than the observed values by a small amount. Part if not all of this discrepancy may be explained by the fact that no account was taken in the computation of the vertical load carried by the top welds.

Column 10, predicted ultimate load on weld strength, should show relationship to column 8, the ultimate load. According to reasoning, column 8 values should be less than those of column 10 because the top welds were subjected to tearing stresses due to deformation of the web and of the top plate. As will be noted these tearing stresses were not so important as to cause actual failure much before predicted failure.

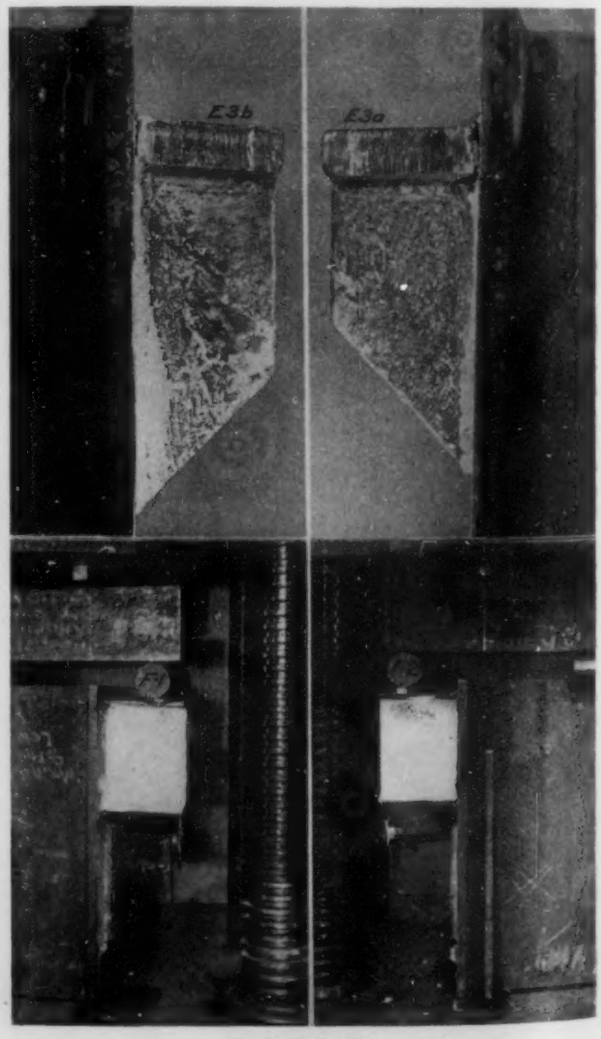


Fig. 6—Bracket Tests

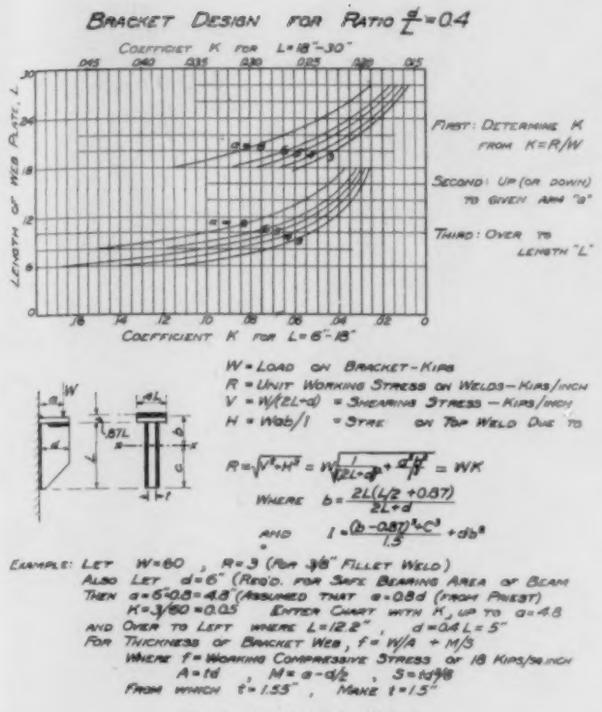

BRACKET DESIGN FOR RATIO a/L = 0.4
COEFFICIENT K FOR L=18"-30"
LENGTH OF WEB PLATE, L
COEFFICIENT K FOR L=6"-18"
FIRST: DETERMINE K FROM K=R/W
SECOND: UP (OR DOWN) TO GIVEN ARM "a"
THIRD: OVER TO LENGTH "L"
W = LOAD ON BRACKET - KIPS
R = UNIT WORKING STRESS ON WELDS - KIPS/INCH
V = W/(2L+a) = SHEARING STRESS - KIPS/INCH
H = Wab/I = STRESS ON TOP WELD DUE TO
WHERE b = 2L(L/2 + 0.87)/(2L+d)
AND
EXAMPLE: LET W=60 , R=3 (FOR 3/8" FILLET WELD)
ALSO LET d=6" (REQ'D. FOR SAFE BEARING AREA OF BEAM
THEN a=5+0.8=4.8" (ASSUMED THAT a=0.8d (FROM PRIEST)
K=3/60=0.05 ENTER CHART WITH K, UP TO a=4.8
AND OVER TO LEFT WHERE L=12.2" , d=0.4 L=5"
FOR THICKNESS OF BRACKET WEB, f=W/A + M/S
WHERE f=WORKING COMPRESSIVE STRESS OF 18 KIPS/SQ.INCH
A=td , M=a-d/2 , S=td²/6
FROM WHICH t=1.55" , MAKE t=1.5"

Fig. 7—Chart for Bracket Design

Columns 11 and 12 show design loads. Note that in most cases the web and weld were rated as of about equal strength. Column 13 has been included to show ratio between load at appearance of first strain and the load at which the strain lines were generally distributed over the web. Two specimens show high ratios and a study of these specimens leads the writer to believe that the first strain lines appeared prematurely, possibly due to locked-up welding stresses and that no particular significance can be attached to these unusual values.

Columns 14 to 17 contain different ratios of actual to design loads and might be termed factors of safety. Since steel beams and columns in structures have approximate ratios of design to yield-point loads of two to three, the ratios given in column 15 may appear somewhat conservative. If so, the same design formula for thickness may be used but the working stress, f, can be raised as desired. Column 14 does not give true values since the webs in all cases except two were still carrying load at the ultimate load point, although in many cases they were deforming badly. Column 17 gives what might be termed the true factor of safety since failure actually took place in the top welds. These ratios are nicely in agreement with the value of 4 which is commonly specified for welds subjected to static loads. No comment is offered for column 16 except to say that it is presented to those who feel that the web of the bracket must never in any part exceed the yield point even though it might be shown that a slight yielding is not harmful and that the webs have a goodly quantity of reserve strength.

In conclusion it should be noted that all of the brackets tested gave good results and that, therefore, the selection of bracket shape should be based on economy and on architectural limitations.

Acknowledgment

I take this occasion to express gratitude to Inge Lyse and his staff at Fritz Laboratory for cooperation in this project, and in particular to C. C. Keyser, our laboratory expert, for an excellent job of welding.

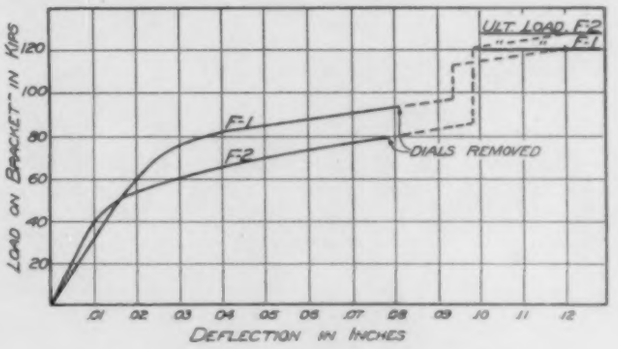


Fig. 8—Load-Deflection Curves for Specimens F-1 and F-2

Welding Research

(*Continued from page 1*)

of larger magnitude than the actual cash contribution.

In addition to the funds required for these Subcommittees, the Main Committee must have an office, a paid Secretary or Director (as the Chairman is serving without remuneration and can only devote a small part of his time to this work), and a stenographer. This office will also serve as a clearing-house for the work of the subcommittees, as well as provide space for the staff of the the Literature Committee.

An office of moderate size in the Engineering Societies Building has already been engaged which will probably serve for the coming year. Mr. William Spraragen, Technical Secretary of the AMERICAN WELDING SOCIETY and Editor of its JOURNAL, is already giving half of his time as Secretary of the Main Committee and of its subcommittees. Dr. G. E. Claussen has already been working for several months in making critical abstracts of literature and will be located in this office.

In order to be efficient, the growth of the paid staff will naturally be a slow one, particularly when it is realized that some of the tasks involved require unusual ability, and that the funds of the Committee are not sufficient to pay for such ability at commercial rates. It is hoped, however, that the unusual opportunities offered to able young men in this field will attract them at salaries somewhat lower than they might obtain from industry.

A brief consideration of the above plans will indicate to any one familiar with such organizations that even for the first year a total budget of $25,000 is a modest one. Moreover, the number of industries actually concerned with welding is so great that the contributions from individual concerns need not be large.

C. A. Adams, *Chairman,* **Welding Research Committee**

Electric Heating by the Proximity Effect*

By EDWARD BENNETT†

1. *The Proximity Effect*

IF an alternating current flows in the long narrow rectangular loop of wire illustrated in Fig. 1, the sinusoidal variation in the current in the loop induces a definite distribution of electric intensities at all points of the surrounding space. These electric intensities vary in sinusoidal manner and they give rise to a distribution of alternating currents in any conducting materials in the neighborhood of the loop.

If the equation for the aternating current in the arrow direction around the loop is,

$$i \text{ (amperes)} = I \sin 2\pi ft \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

the value of the induced electric intensity **F** in the arrow direction at any point P which is not too far from the loop and from the plane *abcd* which is perpendicular to the loop at its mid-point is, given with fair precision by the expression—

$$\mathbf{F} \text{ (volts per meter)} = -\mathbf{s}_1 \mu_0 f I \log \frac{h_2}{h_1} \cos 2\pi ft \ldots . (2)$$

in which,

h_1 and h_2	represent the perpendicular distances from the long legs of the loop to the point P,
μ_0	represents the permeability of free space in the *mks* system. $\mu_0 = 4\pi\ 10^{-7}$,
$\mathbf{s}_1$	represents a unit vector at the point P drawn parallel to the long legs and pointing in the arrow direction along that leg which is at the distance h_1 from P.

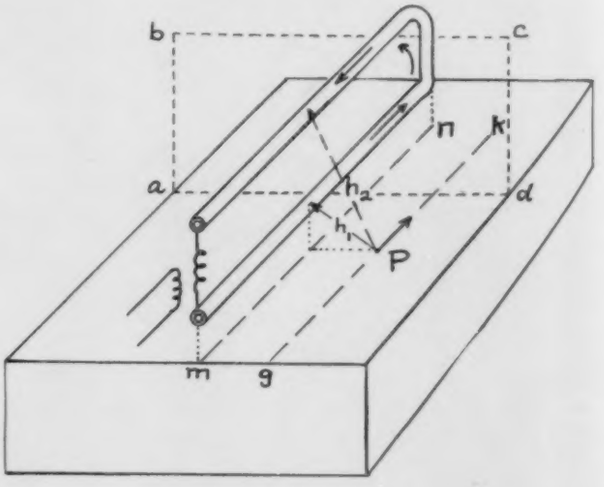
This expression does not hold for points near the ends of the loop.

In Fig. 1 the loop is represented as mounted above a slab of conducting metal. For this arrangement, the ratio h_2/h_1 will be a maximum for points along the line *mn* which lies on the surface of the slab immediately below the lower leg of the loop. From equation (2) it follows that the electric intensities will be greatest along the line *mn*. In any other line as *gk*, either on the surface of the plate or below its surface, the intensities will be smaller and smaller as *gk* is taken at greater and greater distances from the projection *mn*.

The distribution of electric intensities pictured above gives rise to a distribution of induced currents in the conducting plate, the current density being a maximum along the projection *mn*. Along the line *gk*, the current density becomes less and less, and lags more and more behind the current density in *mn*, as the line *gk* is taken at greater distances from *mn*.

From equation (2) it is seen that the electric intensities due to an alternating current having a given value I (say 5000 amperes) are directly proportional to the frequency of alternation. By mounting an inducing water-cooled copper loop with its lower leg in *close proximity* to the surface of a steel plate (3 mm. between copper and steel), and by using an inducing current having a frequency in the audio range (1000 to 20,000 cycles per second), the induced current is so concentrated in a thin narrow strip of the steel immediately under the leg in close proximity, that it is possible to heat this narrow strip to the melting point without greatly heating the surrounding metal. Moreover, if the leg of the loop which is parallel to and in close proximity to the surface of the plate is not straight but contains curved or zigzag portions, the narrow strip containing the high induced current densities conforms to the zigzagged projection of the leg on the plate. This effect, namely, the *concentration* of an alternating current in certain portions of a conductor which occurs when a second conductor carrying an *alternating current* is brought into proximity to the first, is called the *proximity effect.*

Fig. 1—An Inducing Loop



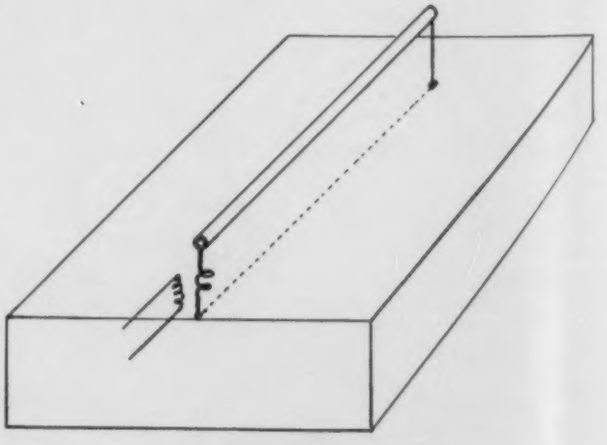
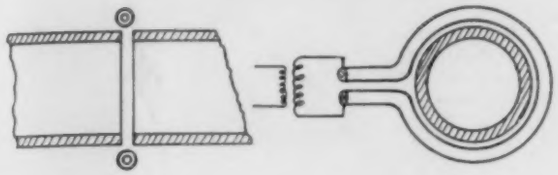


Fig. 2—A Single Inducing Conductor

* Contribution to Fundamental Research Committee. To be presented at Annual Meeting, A. W. S., Cleveland, Oct. 1936.

† Department of Electrical Engineering, The University of Wisconsin.

Fig. 3—Strip Heating by an Inducing Coil



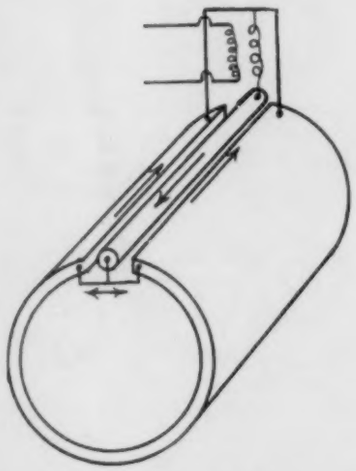


Fig. 4—Connections for an Auxiliary Conductor Which Determines the Path of the Heating Current

2. Electrical Connections for Causing the Concentration of Heating Currents in Narrow Strips

Figures 1 to 6 show different arrangements for utilizing the proximity effect to cause heating currents to concentrate in selected narrow strips of conducting bodies. The only feature of the source of audio frequency current which is represented in these diagrams is the transformer which is needed to transform the current delivered by the source to the large values necessary for rapid heating.

The arrangement shown in Fig. 1 would not be used in practice since the return current in the upper leg operates to partly neutralize the concentration caused by the outgoing current in the leg in close proximity to the plate. By bringing the return current back through the plate as in Fig. 2, a higher concentration of current is obtained, the power losses which occur in the upper leg of Fig. 1 are eliminated, and the power factor of the circuit is improved. However, the complete inducing loop with no conductive connection to the body to be heated would be used in the arrangement illustrated in the two views of Fig. 3. Here the inducing current flows in a water-cooled copper tube and induces heating currents in narrow strips on the ends of the two pipes encircled by the tube.

Figure 4 is another arrangement, similar to Fig. 2, in which the auxiliary water-cooled inducing conductor is connected in series with the plate to be heated. Here the inducing conductor is mounted between the edges of a tubular blank for the purpose of confining the return current to those edges of the blank which are to be heated for welding. The auxiliary conductor is withdrawn before the edges are brought together. Figures 5 and 6 show arrangements in which the *auxiliary* water-cooled inducing conductor is dispensed with and in which, by appropriate connectors, the heating current is confined to layers a few millimeters or centimeters deep along the adjacent edges of steel plates and pipes. In these figures the adjacent edges have the appearance of being widely separated, but in practice the separation between edges is of the order of a few millimeters.

In all of these arrangements, the arrows represent the direction of the current at a given instant of time in various parts of the circuit. It will be seen that to confine heating currents to narrow strips of large conducting bodies, three conditions must be satisfied.

a. The strip of the conducting body in which heating current is to be caused to concentrate must be selected and predetermined by so shaping, proportioning and mounting another electric conductor that some portion of this second conductor extends along the selected strip in close proximity to it.

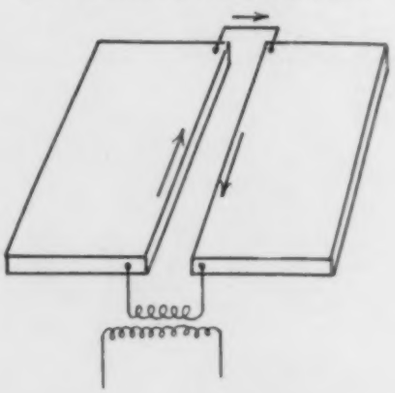
b. The bodies (and the auxiliary conductor, if any) must be so connected to the source of alternating current that the current flows in opposite directions in the two closely adjacent edges, conductors or strips. (In the inductive case, the induced current is approximately in phase opposition to that of the inducing current.)

c. For effective concentration of the current in narrow strips, the frequency of the heating current must be much higher than the commercial power frequencies of 60 cycles per second and should be in the audio frequency range of 1000 to 20,000 cycles per second. The control over the pattern according to which the current densities are to decrease from the center line to the edges of the selected strip and from the surface of the strip to the interior of the body is had by the joint adaptation of three things to bring about the desired pattern. These three things are, the frequency of alternation of the heating currents, the distance from the surface of the strip to the second conductor, and the width and cross-sectional shape of this second conductor. A high frequency, a short distance between the surface of the strip to be heated and the second conductor, and a narrow second conductor lead to the concentration of the heating current in a shallow narrow strip.

3. The Distribution of the Current Densities.

For none of these configurations is it feasible to precisely compute the distribution of the current densities in

Fig. 5—Connections for Heating Edges of Plates



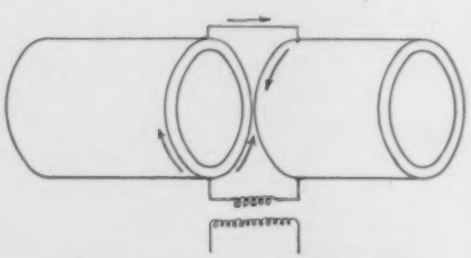


Fig. 6—Connections for Heating Ends of Pipes

the body to be heated. This is particularly true for the ferromagnetic materials at temperatures below the non-magnetic state, because of the non-linear relation between the magnetic flux density and the magnetizing current throughout the hysteresis cycle, and because of the further complication that the peak magnetic intensities acting on different layers of steel drop from a value expressed in hundreds of ampere-turns per cm. at the surface of the steel to less than one per cent of this value in layers a centimeter below the surface. The precise calculation is further complicated by the fact that the water-cooled auxiliary conductors must be of appreciable cross section in order to carry the heavy currents, and the proximity effect operates to produce an unknown and non-uniform distribution of the current over the cross section of the auxiliary conductors.

However, by making two assumptions it is possible to derive equations for the distribution of the current density over the cross section of a thick slab which serves as

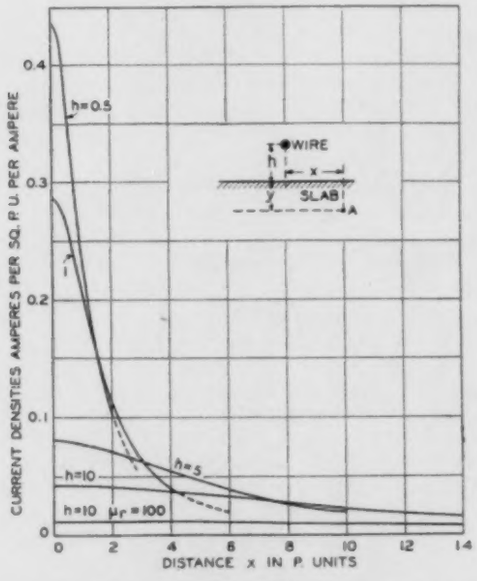


Fig. 7—Current Densities at the Surface of a Slab for Different Mounting Heights

Current densities are expressed in amperes per sq. penetration unit per ampere of heating current
The distances *x* and *h* are expressed in penetration units

the return for the outgoing current in a long straight conductor mounted above and parallel to the surface of the slab as illustrated in Fig. 2. The curves of current density plotted from these equations give a good insight into the phenomena exhibited by the actual materials.

The two assumptions are: (1) that the inducing current in the water-cooled conductor is not distributed over the cross section of the inducing conductor but is all concentrated in a line constituting the axial center of the actual distribution; (2) that the permeability of the ferro-magnetic material is constant and has a value 5, 10 or 100 times that of air, depending upon the magnitude of the currents used. Of course this assumption is not necessary for the non-magnetic metals, nor for the ferric metals after they attain temperatures above the non-magnetic point, since for these materials, the permeability is constant and is substantially that of air.

In writing the equations which have been derived for the distribution of the current densities and in plotting the results in the form of curves, it is very helpful to express all linear dimensions, not in centimeters, but in

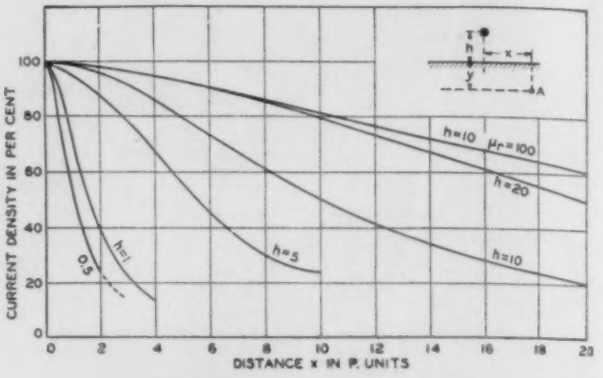


Fig. 8—Current Densities at the Surface of a Slab

For each height of wire, the current densities are expressed in per cent of the current density existing immediately under the wire at that height
The distances *x* and *h* are expressed in penetration units

terms of a unit of length which is appropriate to the physical problem in hand. The great advantage of using a unit of length appropriate to this physical problem is that it enables us to represent the distribution of current for a wide range of conducting materials, spacings and frequencies by a very few curves. We will name the appropriate unit of length for this problem the *penetration unit* for the material and the frequency under consideration. This name has been applied to the unit since the length of the appropriate unit is an indication of the depth to which the heating current *penetrates* beneath the surface of the slab. For example, the equations show that at a depth of 1 penetration unit below the surface of the slab of Fig. 2, the current density is approximately $(1/\epsilon)$th (36.8 per cent) of the density at the surface and it lags by 1 radian behind the current density at the surface.

The length of the *penetration unit* for a particular conducting material and at a particular frequency of f cycles per second is given by formula (3).

$$1\ P.\ \text{unit (in meters)} = \frac{1}{\sqrt{\pi f \mu \gamma}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

γ represents the conductivity of the conductor in mho-meters.

μ represents the permeability of the conductor in webers, amp-turns, meter. $\mu = 4\ \pi\ 10^{-7}$ for non-magnetic materials.

The values of the penetration unit for different materials and frequencies are as shown in Table 1.

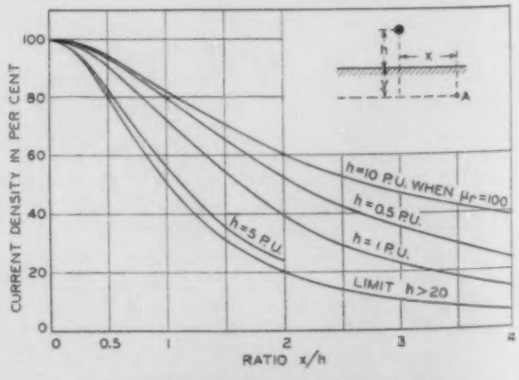


Fig. 9—Current Densities at the Surface of Angle

For each height of wire, the current densities are expressed in per cent of the current density existing immediately under the wire at that height
The distance is expressed in penetration units

Table 1 Values of the Penetration Unit for 4000 Cycles per Second

Material		Relative Resistivity	Permeability	Conductivity mho-meter		P. unit cm.
Copper	20° C.	1	1	5.8	10^7	0.105
Steel	20° C.	11	100	5.27	10^6	0.035
Steel	800° C.	94	1	6.17	10^5	1.01
Steel	1300° C.	100	1	5.8	10^5	1.05
Allegheny metal	20° C.	40	1.02	1.45	10^6	0.65
Monel metal	20° C.	25	1	2.32	10^6	0.525

By making the two assumptions stated above relative to Fig. 2, and by seeking the solution of Maxwell's field equations which will also satisfy the boundary conditions in Fig. 2, it is found that the current density C at any point A in an extended conducting metal slab whose depth is 5 or more times the penetration unit may be computed from the Fourier integral written in equation (4).

$$C = \frac{j\,2\,I}{\pi}\int_0^\infty \frac{\cos xb \exp\left(-hb - y\sqrt{b^2 + 2j}\right)}{\sqrt{b^2 + 2j} + b\mu_r}db \quad . . (4)$$

in which

- C represents the value of the current density at the point $A = x, y$, in amperes per square penetration unit.
- I represents the value of the current in the inducing conductor, in amperes. Both C and I represent r. m. s. values.
- h represents the height above the surface of the axis of the inducing current.
- y represents the depth of the point A below the surface.
- x represents the X coordinate of the point A.
- μ_r represents the relative magnetic permeability of the conducting slab.
- b represents the variable of integration, this disappears from the integral upon substituting the two limits 0 and ∞.
- j represents $\sqrt{-1}$

(The values of x, y and h are to be expressed in P. units.)

If the slab is of non-magnetic material or of ferromagnetic material at temperatures above the point at which the material becomes non-magnetic, μ_r has the value unity and equation (4) reduces to the simpler form (5).

$$C = \frac{I}{\pi}\int_0^\infty [\sqrt{b^2 + 2j} - b] \cos xb \exp\left(-hb - y\sqrt{b^2 + 2j}\right)db \quad . . . . . (5)$$

For mounting heights for the auxiliary conductor in which h is greater than 20 penetration units, equation (5) for non-magnetic materials evaluates to the simple form (6).

$$C = \frac{1+j}{\pi}\,\frac{h}{h^2 + x^2} \exp - y\,(\cos y - j \sin y)\,I \quad . . . . (6)$$

From Table 1 it will be seen that the value of the penetration unit for steel at a frequency of 4000 cycles per second ranges from 0.035 cm. for cold steel with an assumed relative permeability of 100 to 1.05 cm. for steel at a temperature of 1300° C. For the case in which the axis of current in the water-cooled inducing conductor of Fig. 2 is 1 cm. above the surface of a steel slab, we are interested in curves showing the distribution of the current in the slab for the range of mounting heights in which h lies between $h = 1$ and $h = 30$ penetration units.

From the integral equations 4 and 5, sets of curves have been plotted in different forms to show the distribution of the current density in a wide slab of steel whose depth is 5 or more times the penetration unit. (With the exception of the curves marked $\mu_r = 100$, all the curves are for non-magnetic materials or for steel in the non-magnetic state. The curves marked $\mu_r = 100$ are for steel having an assumed constant permeability equal to 100 times that of air. The curves for $\mu_r = 100$ give only a rough indication of the current distribution in magnetic materials. They do show the effect of the higher permeability in confining the current to a thinner surface layer of the steel and in causing a wider spread of the heating current.

The curves plotted in Fig. 7 show the manner in which the current-density in the surface film of the slab falls off on each side of the center line of the heated strip. Each curve is for the mounting height of the inducing conductor indicated on the curve. For this figure, the current densities are plotted in amperes per square penetration unit per ampere of heating current flowing in the inducing conductor (or in the slab). The effect of the close proximity of the inducing conductor in bringing about high current densities along the center line of the strip and in decreasing the width of the heated strip is well brought out by these curves.

The data used in plotting the curves of Fig. 7 have also been plotted in another form in the corresponding curves of Fig. 8. In Fig. 8 in plotting the curve for any specified mounting height, the current density in the surface along the center line of the strip has been taken as 100 per cent for that curve, and the current densities at other points have been plotted in per cent of the current density in the center line. Accordingly all curves start at 100 per cent, but the 100 per cent points represent quite different current densities for different mounting heights.

In Figs. 7 and 8, distances from the center line of the heated strip have been plotted in penetration units. In Fig. 9 the curves of Fig. 8 have been redrawn by plotting the surface current densities (expressed in per cent as in Fig. 8) against distances expressed, not in penetration units, but in terms of the mounting height of the inducing conductor above the slab. The purpose in using the mounting height as the unit of length is to bring out the relative rôles played by high frequency of alternation and close proximity between the inducing conductor and the slab surface in narrowing the width of the heated strip. For example, suppose that the inducing conductor is mounted with its current axis at a height of 2 cm. above a steel plate at a temperature of 800° C., and that the frequency is 1000 cycles per second. For these conditions, the penetration unit is 2 cm. Accordingly, the mounting height of the inducing conductor is 1 P.U., and the concentration pattern is shown by the curve of Fig. 9 marked $h = 1$ P.U. Suppose the attempt is now made to concentrate the current in a narrower strip by using a higher frequency while keeping the conductor axis fixed at 2 cm. above the plate. If the frequency is increased to 25,000 cycles per sec., the penetration unit becomes 0.4 cm, and the mounting height becomes 5 P.U. Accordingly, the current distribution will be that shown by the curve marked $h = 5$ P.U. No matter how great the frequency is made, the current will not be more concentrated than the pattern shown by the limiting curve which is marked $h > 20$ P.U. On the other hand, if the frequency is held at 1000 cycles per sec. but

the mounting height is reduced from 2 cm. to 1 cm., then the mounting height is now $h = 0.5$ P.U., and the concentration pattern will be obtained from the curve so marked. But for this curve, unit value of the ratio x/h represents 1 cm. instead of 2 cm. as for the previous curves. Hence, before the $h = 0.5$ P.U. curve can be directly compared with the curves for the 2 cm. height, the 0.5 P.U. curve must be redrawn by dividing all its x values by 2. Upon doing this, it may readily be seen that reducing the mounting height from 2 cm. to 1 cm. and at the same time keeping the frequency constant at 1000 cycles per sec. concentrates the current in a narrower strip than does the raising of the frequency from 1000 to 25,000 cycles with a mounting height of 2 cm.

To show the distribution of the current densities in planes below the surface of the slab, the curves of Figs. 10 and 11 have been drawn for the case in which the mounting height of the inducing conductor is 1 penetration unit. The three curves of Fig. 10 show the distribution of current density in three planes parallel to the surface—the first plane on the surface and the second and third planes being 1 and 2 penetration units below the surface, respectively. At points in these last two planes, the current densities lag 1 and 2 radians behind the current densities at corresponding points in the surface and have decreased to $(1/\epsilon)$ th and $(1/\epsilon)^2$ of the values at the surface. The curves of Fig. 11 show the values and phase angles of the current densities at points in vertical planes spaced at intervals of 1 P.U. from the mid plane of the strip.

4. *Applications of the Proximity Effect*

The proximity effect method of heating is a method of selectively heating narrow shallow strips on the surface or the edges of large metallic bodies by causing the heating current to concentrate in the selected strips. Its field of application is to industrial heating operations in which it is necessary to heat the edges or narrow surface strips of metallic conductors, particularly ferromagnetic materials, for such purposes as brazing, welding, annealing, hardening, enameling or alloying. The method requires the use of alternating currents at frequencies in the audio range of 500 to 20,000 cycles per second. Frequencies of the order of 500 cycles are suitable for certain heating operations on heavy steel plates and vessels in which the temperature is not to be carried much above the non-magnetic point. For heating narrow strips on the edges of steel plates to welding temperatures, and for the effective heating of nonmagnetic metals, frequencies of the order of 2000 cycles per second and higher seem essential. Actual experience has not been obtained with *large sources of power* at the higher frequencies, and the properties of and results from large scale generating and transforming equipment for the higher frequencies remain to be determined.

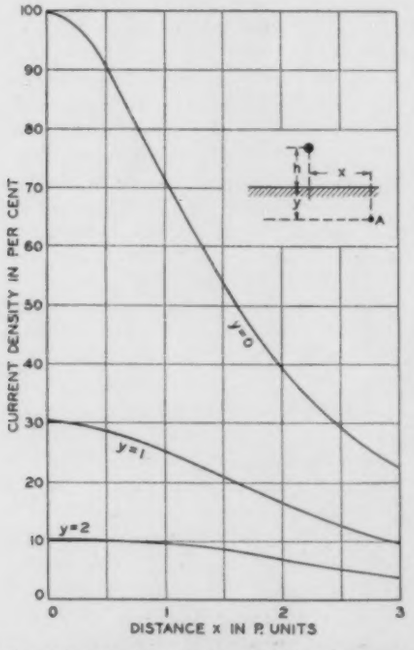


Fig. 10—Current Densities for a Mounting Height of One Penetration Unit

The current densities are given in per cent of the current density directly below the wire. x, y and h are in penetration units

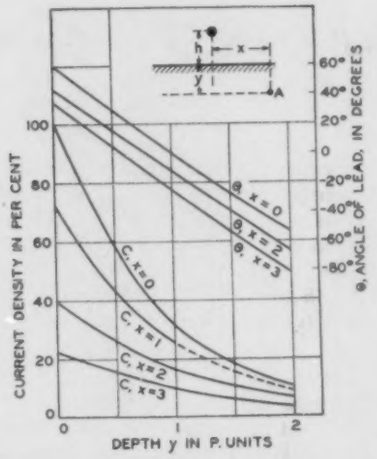


Fig. 11—Current Densities and Phase Angles for a Mounting Height of One Penetration Unit

The current densities are given in per cent of the current density directly below the wire
x, y and h are in penetration units
The phase angles are the angles by which the current density leads the heating current

The heating currents required are in the range of 3000 to 20,000 amperes, depending upon the frequency and the thickness of the material to be heated. These currents will be applied to the work at voltages ranging from 20 to 1000 volts, again depending upon the frequency and the length of the strip to be heated. The power factor across the secondary terminals of the transformer will range between 20 and 60 per cent. At the higher voltages the low power factors can be corrected at very little expense by capacitors connected across the secondary terminals of the transformer.

A number of the properties of the circuits and arrangements used to concentrate the current turn out to be of a nature to lessen, rather than to increase, the difficulties in applying the method. For example, if the inducing conductor in Fig. 4 is displaced from a central position, the forces acting upon it are repulsive and tend to center it between the edges of the blank, rather than to draw it closer to the nearer edge. Again, in this same arrangement, if an arc strikes between the inducing conductor and the heated edge of the plate, the direction of the magnetic field is such as to drive the arc with great speed to that point in the gap at which there is no difference of potential between the inducing conductor and the heated edge of the blank, and the arc thereupon extinguishes.

Arc Welding of Structural Alloy Steels

By W. L. WARNER,[1] WATERTOWN, MASS.

The author discusses the effect of welding heat on different structural alloy steels. This heat effect, expressed in terms of Vickers Brinell hardness, is affected by the physical and chemical properties of both the parent metal and the electrode used. The author presents graphs showing the extent of the effect of these properties on the welded structure and on the weldability of the material.

THE EASE or the difficulty with which a steel structure may be fusion-welded successfully depends upon several factors including: (1) The chemical composition of the steel, and (2) the heat effect of welding on the steel. There are, of course, other factors involved, such as heat-treatment of the steel, design of the structure, the type of service for which the structure is intended, and the availability of suitable welding materials and personnel, but the two first mentioned are of fundamental metallurgical importance.

The application of the fusion-welding method in any form necessarily involves the use of heat in order to produce fusion. This requirement is unavoidable. This heat of welding affects certain portions of the steel in the immediate vicinity of the weld in the process of depositing the molten metal which forms the weld. The zone of the base metal which is affected by the heat of welding is called the "heat-affected zone."

When considering this zone adjacent to the weld which has been affected by the heat of welding, it must be remembered that the width of the heat-affected zone and the degree of hardness formed are dependent upon the mass of the piece, the welding energy used, and the amount of heat input per unit of length of weld or the rate of travel of the welding arc, as well as the plate composition. Therefore, in making comparisons between different steels as to heat effect of welding, such factors as the mass of the pieces and the welding conditions must be similar or incorrect comparisons will be obtained. Also, it is desirable to make the comparisons of heat effect under conditions which give as nearly as possible the steepest temperature gradient obtainable under practical welding conditions.

The practice at the Watertown arsenal is to make comparisons of heat effect on plate metal 1/2 in. thick. Single beads of weld metal are laid approximately 3 in. long on a piece of plate approximately 3 in. wide and 9 in. long. The bead is laid lengthwise of the piece approximately in the center, and when cold, a piece about 1/2 in. wide is cut through the bead and plate about 1 in. from the start of the bead. This piece is surface-ground on both cut surfaces to give true parallel faces for hardness measurements by the Vickers method. Figs. 1, 2, and 3 show Vickers hardness surveys taken on sections of weld beads run with both slow and fast welding speeds.

Comparisons of heat effect on different steels are generally made in the as-welded condition, and subsequently the effect of stress relieving or other heat-treatment is determined, but the basic comparison is made on the as-welded specimen. There are good and valid reasons for this procedure.

Determinations of heat effect on cross sections of multiple-layer welds give valuable and interesting data, but the result obtained shows the final heat effect due to the multiple-layer procedure. A heat-effect test of this nature does not usually show the maximum hardening effect on the base metal, which occurs when the first layer is deposited on the cold plate, and it is at this point in the making of a weld that cracks may start due to the heat effect on the base metal. The heat of subsequent layers, if applied within a reasonable time, will greatly reduce the heat effect of the first layer applied. Hence, the result obtained from a hardness survey on the cross section of the finished weld does not indicate how dangerous or how critical may have been the situation when the first layer was applied.

Therefore, in this study of heat effect on the base metal, we are trying to determine the maximum hardness formed in the heat-affected zone under the worst conditions of rapid heating and cooling, for after the weld has been finished and given a stress-relieving heat-treatment, the danger of plate or weld cracking due to high hardness in the heat-affected zone is past.

The chemical composition of the base metal also has a pronounced affect on the hardness formed in the heat-affected zone. The element mostly responsible for the hardening is carbon. The metallic elements are contributory only and serve rather to intensify the hardening effect of the carbon than as hardening elements themselves.

In Fig. 4 are shown hardness curves of weld metal and of the heat-affected zone on plain carbon steels ranging from about 0.15 to 0.50 per cent carbon. These weld beads were deposited on flat plate 1/2 in. thick, 9 in. long, and approximately 3 in. wide. The weld beads were laid the entire length of the 9-in. piece by automatic welding, using a high current of the order of 350–400 amp. Therefore, the results shown are not directly comparable with those shown in Figs. 1, 2, and 3, which are hand welds, because the amount of heat put into each specimen by the automatic welds was far greater than that put into the hand-welded specimens; although the plate pieces used in both cases were the same size. If, instead of running the weld beads the entire length of the 9-in. piece, the beads had been run only 3 or 4 in. long in the center, it is the author's opinion that the curves shown in Fig. 4 would have shown considerably higher hardnesses even in the lower carbon range.

The curves shown in Fig. 4 have a considerably steeper slope in the higher carbon range from 0.30 to 0.50 per cent than in the range from 0.15 to 0.30 per cent. The author believes that this difference is similarly true of nearly all steels as far as heat effect of welding is concerned. Any one who believes that fifteen points of carbon do not have much effect on the hardness of the heat-affected zone, therefore, must qualify his statement before

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Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until December 10, 1936, for publication at a later date. Discussion received after the closing date will be returned.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

A contribution to the Industrial Research Subcommittee of the Welding Research Committee of the Engineering Foundation.

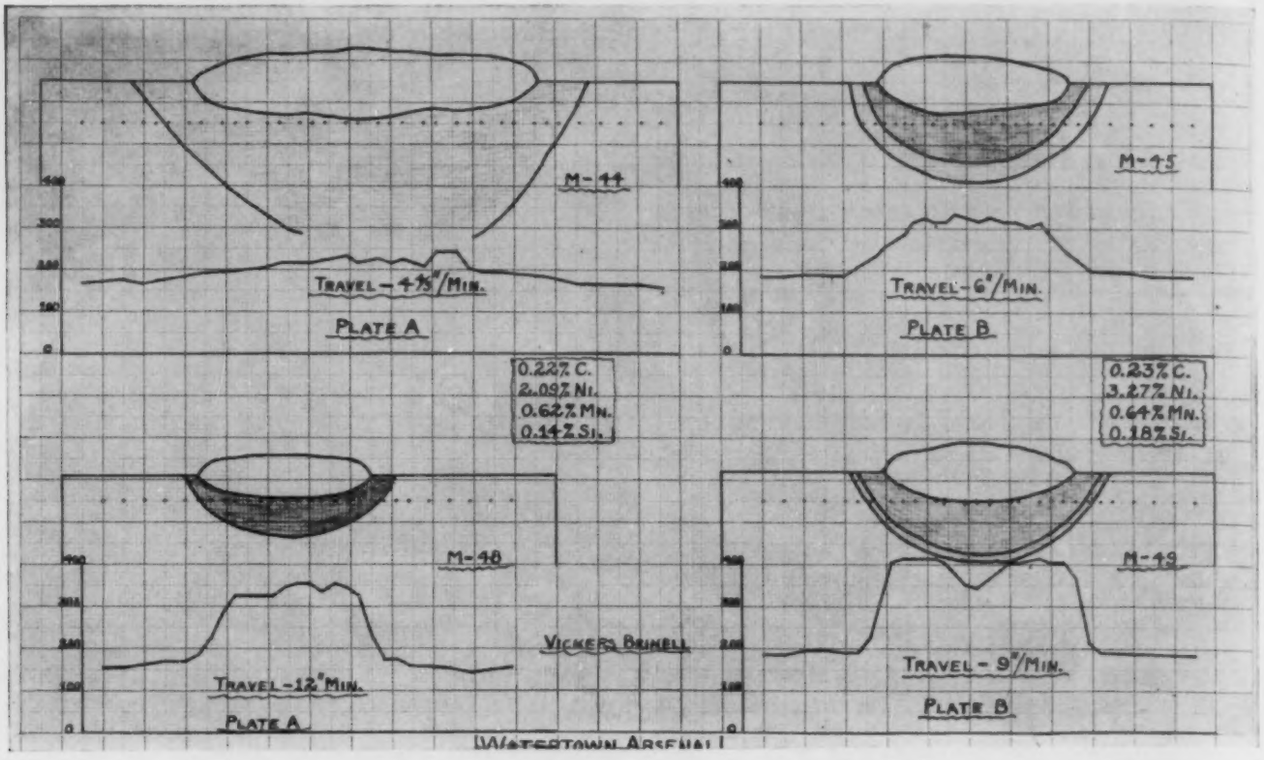

FIG. 1 EFFECT OF WELDING HEAT ON 1/2-IN. NI STEEL PLATE

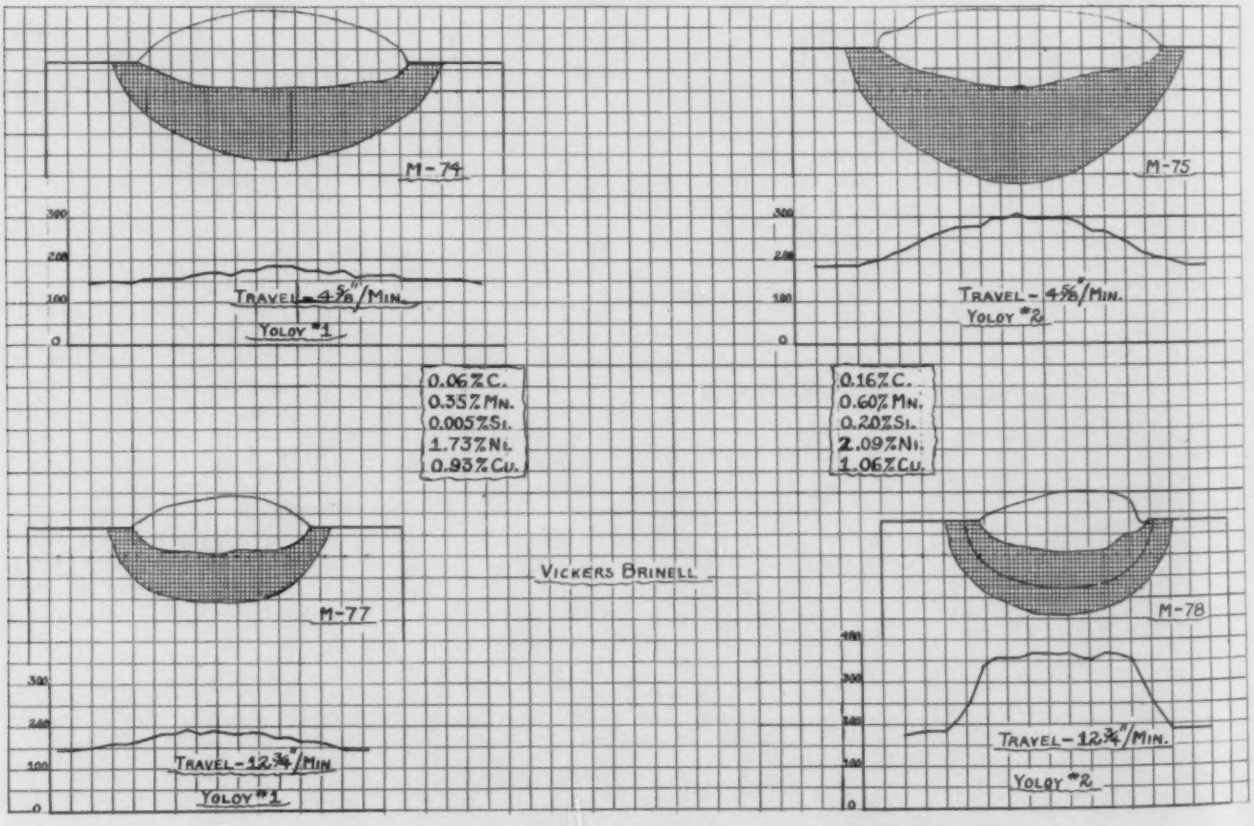

FIG. 2 EFFECT OF WELDING HEAT ON 1/2-IN. NI-CU STEEL PLATE

TABLE 1 CHEMICAL AND PHYSICAL PROPERTIES OF PLATE AS ROLLED[a]

Plate No.	Material	Chemical composition C	Mn	Si	Ni	Mo	Cu	P	Cr	Physical properties, not welded: Tensile strength, lb per sq in. As rolled	Stress rel'd	Elastic limit, lb per sq in. As rolled	Stress rel'd	Elong. in 1 in., % As rolled	Stress rel'd	Tensile impact, ft-lb As rolled	Stress rel'd
1	3½% Ni	0.35	0.62	0.16	3.37	..	..	..	0.22	107,000	100,000	55,000	61,000	35.0	40.0	810.0	820.0
2	3½% Ni	0.23	0.64	0.18	3.27	..	..	..	..	90,000	84,000	50,000	57,000	40.0	50.0	750.0	768.5
3	2% Ni	0.22	0.62	0.14	2.09	..	..	..	..	80,000	75,000	42,000	50,000	50.0	60.0	790.0	829.7
4	Cu-Ni-Mo	0.23	0.72	0.02	0.79	0.15	1.56	0.02	..	105,000	89,000	58,200	60,000	40.0	48.0	773.0	778.3
5	Cu-Ni-Mo	0.09	0.85	0.03	1.08	0.10	1.60	0.02	..	86,650	73,000	40,800	50,000	46.5	55.0	740.0	706.1
6	Cu-Ni	0.06	0.35	0.005	1.73	..	0.93	..	..	70,700	67,700	48,400	45,200	56.0	61.0	768.5	730.1
7	Cu-Ni	0.16	0.60	0.20	2.09	..	1.06	..	..	87,300	80,500	54,000	56,000	50.0	51.5	811.8	797.2
8	Cr-Cu-P	0.12	0.40	0.76	..	..	0.39	0.16	1.08	75,800	75,000	43,800	46,200	59.0	59.0	875.3	836.2[b]
9	Mn-Cu	0.30	1.40	0.20	..	..	0.25	..	..	91,400	80,300	45,400	40,000	53.0	58.0	934.0	860.7
10	Mn-Si	0.36	0.76	0.26	..	..	0.03	..	..	96,400	88,500	35,800	36,200	42.5	45.5	894.8	875.3
11	Mn-Mo, no. 1	0.17	1.57	0.43	..	0.38	..	0.02	..	104,000	92,000	36,000	47,000	42.0	46.0	890.0	800.0
12	Mn-Mo, no. 2	0.12	1.00	0.21	..	0.49	..	0.03	..	84,000	80,000	37,000	36,500	54.0	51.0	780.0	800.0
13	Cu-Mo	0.29	0.74	0.24	..	0.22	0.35	0.03	..	90,000	88,000	45,000	50,000	40.0	42.0	810.0	820.0

[a] Each value given in the table is the average of two test specimens.
[b] This value obtained from one specimen only.

TABLE 2 PHYSICAL PROPERTIES OF ARC BUTT WELD AND CHEMICAL PROPERTIES OF ALLOY ELECTRODES[a]

Plate no.	Butt welds[b]: Tensile strength, lb per sq in. As welded	Stress rel'd	Elastic limit, lb per sq in. As welded	Stress rel'd	Elong. in 1 in., % As welded	Stress rel'd	Tensile impact, ft-lb As welded	Stress rel'd	Electrodes: Alloy, % Ni	Mo	Carbon in core wire, per cent	Coating
1	104,000	....	55,000	....	20.5	..	560.0	...	2.5	0.3	0.15	Mineral
2	95,500	....	55,000	....	17.0	..	600.0	...	2.5	0.3	0.15	Mineral
3	85,000	....	49,500	....	23.0	..	670.0	....	2.5	0.3	0.15	Mineral
4	99,250	....	53,000	....	22.0	..	581.6	...	...	0.5	0.13	Organic and mineral
5	85,500	....	44,400	....	32.5	..	688.4	...	...	0.5	0.13	Organic and mineral
6	.....	....	....	....	..	..	...	...	...	...	..	.....
7	.....	....	....	....	..	..	...	...	...	...	..	.....
8	85,350	78,000	46,600	41,600	25.0	26.0	744.4	707.0	...	0.5	0.13	Organic and mineral
9	97,100	87,000	50,000	35,400	26.5	36.0	725.6	641.5	...	0.5	0.13	Organic and mineral
10	97,400	92,000	48,000	44,000	22.5	36.0	698.1	744.6	...	0.5	0.13	Organic and mineral
11	94,870	93,300	55,800	.....	22.0	36.5	614.0	704.0	...	0.5	0.13	Organic and mineral
12	85,600	83,800	51,600	50,000	29.5	38.0	712.2	787.7	...	0.5	0.13	Organic and mineral
13	93,750	86,500	51,200	46,800	37.0	39.0	697.1	753.7	...	0.5	0.13	Organic and mineral

[a] Each value given is the average of two specimens.
[b] Tests not completed.

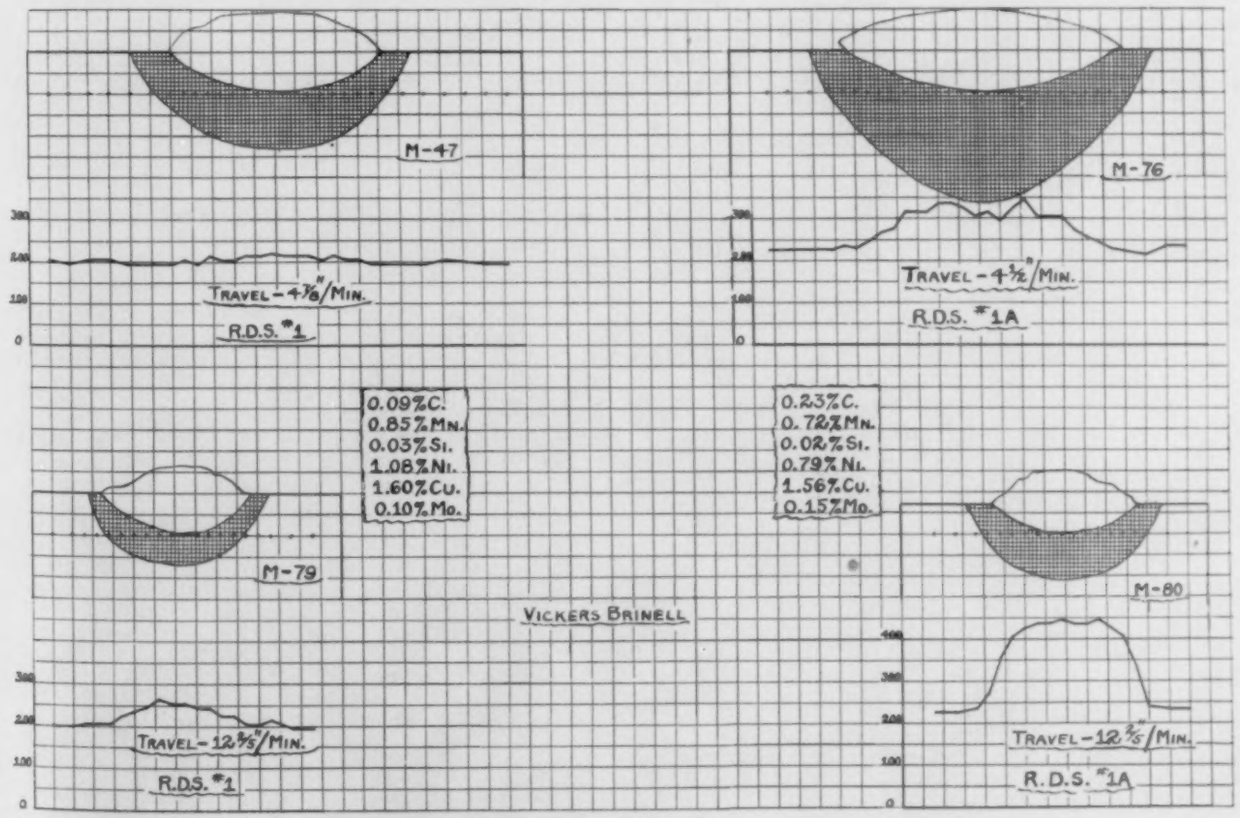

FIG. 3 EFFECT OF WELDING HEAT ON ½-IN. NI-CU-MO STEEL PLATE

expressing himself publicly to that effect. A stress-relieving heat-treatment at 600 C will reduce the hardness of the heat-affected zone to a level slightly higher than the plate metal as rolled.

At the Watertown arsenal the welding characteristics of several of the new low-alloy steels are being studied and compared with structural nickel steel as used by the Ordnance Department of the U. S. Army for the building of gun carriages. The specified physical requirements for this material have been published elsewhere.[2] The method of testing used to determine the tensile properties of the welded joint is as described in that article,[2] although some changes have been made in the shape of the tensile impact specimen for butt joints. The dimensions of the test

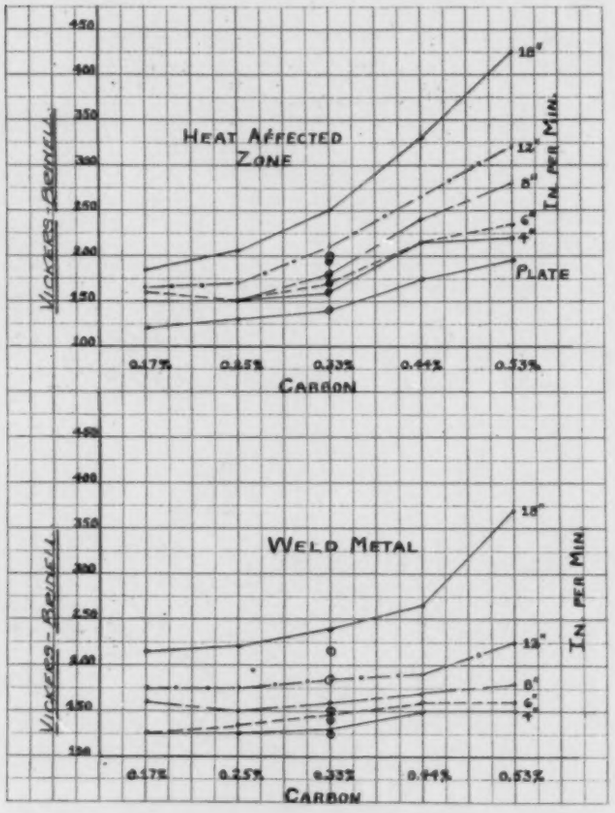

FIG. 4 EFFECT OF HEAT FROM AUTOMATIC WELDING ON 1/2-IN. PLAIN CARBON-STEEL PLATES
(Courtesy of Dr. W. G. Theisinger and Harvard University.)

specimen now used for butt joints are shown in Fig. 5. These dimensions hold for a single V butt joint having a 30-deg bevel or a single U butt joint. The general rule for determining the length of the straight test section is to add 1/4 in. to the width of the weld, or to add 1/2 in. to the width of the groove.

In Table 1 are shown the chemical composition and tensile properties of unwelded 1/2-in. structural alloy-steel plate metals which have been tested at the Watertown arsenal. Table 2 shows the tensile properties obtained from arc butt-welded joints on these plates.

Three commercial types of electrodes, the properties of which are given in Table 3, were used for these welding tests. The properties of the electrode used in welding the structural nickel steels are also given in Table 3.

[2] "Welding of Structural Nickel Steel," by W. L. Warner, *The American Welding Society Journal*, vol. 13, June, 1934, pp. 15–23.

TABLE 3 PROPERTIES OF ELECTRODES USED IN WELDING THE ALLOY-STEEL PLATES

Plate	Electrode type	Carbon in the core wire, per cent	Coating	Alloy in the weld deposit, per cent Mo	Ni
Low-alloy steel	1	0.15	Organic and mineral	0.5	...
	2	0.25	Mineral	0.5	...
	3	0.15	Mineral	...	...
Ni steel	..	0.15	Mineral	0.3	2.5

TABLE 4 VALUES OF MAXIMUM HEAT EFFECT

Plate[a]	Carbon, per cent	Vickers Brinell hardness after welding with arc speeds of— 4 to 6 in. per min	10 to 12 in. per min
1	0.35	490	540
2	0.23	330	410
3	0.22	240	360
4	0.23	340	450
5	0.09	220	260
6	0.06	190	190
7	0.16	310	370
8	0.12	270	...
9	0.30	350	...
10	0.36	320	...
11	0.17	287	397
12	0.12	221	270
13	0.29	258	413

[a] See Table 1

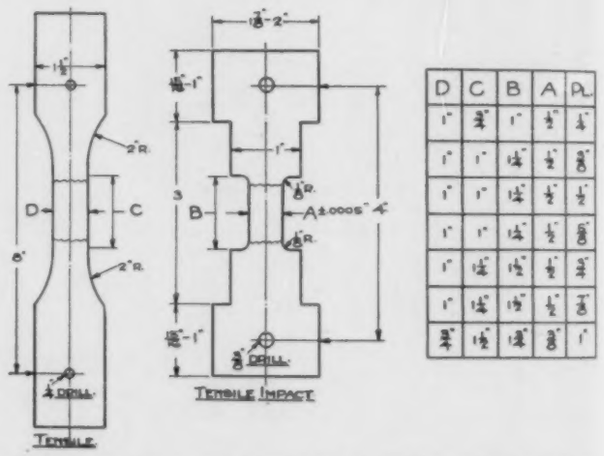

FIG. 5 DIMENSIONS OF TENSILE-TEST SPECIMEN FOR BUTT WELDS AS USED AT THE WATERTOWN ARSENAL

All of the electrodes listed in Table 3 gave good arcing characteristics and sound welds with the exception of electrode No. 3. On the copper-nickel steels and those containing high phosphorous, chromium, and copper, electrode No. 3 gave a porous weld metal. However, the tensile properties of this porous weld metal were good, in some cases nearly equaling those obtained with the alloy electrodes. Figs. 6 and 7 show data on two grades of steel from which a comparison between the low-carbon and the alloy electrodes may be made. The low-carbon weld values are shown by the two blocks at the right in each group of each figure as indicated thereon. On the other steels tested, the comparison between electrodes was quite similar.

In Table 4 are shown the maximum hardnesses set up in the heat-affected zones of the various plate materials listed in Table 1. These hardness values have been determined by the procedure previously described and illustrated in Figs. 1, 2, and 3.

If these maximum hardnesses are compared with the corresponding plate composition as given in Table 1, some conception is obtained of the hardening effect of the alloying elements and the relation between this hardening effect and the amount of the element present in the steel. Such a comparison is shown in Fig. 8. At the top of the left-hand column are shown the values of maximum hardness found in the heat-affected zone with the

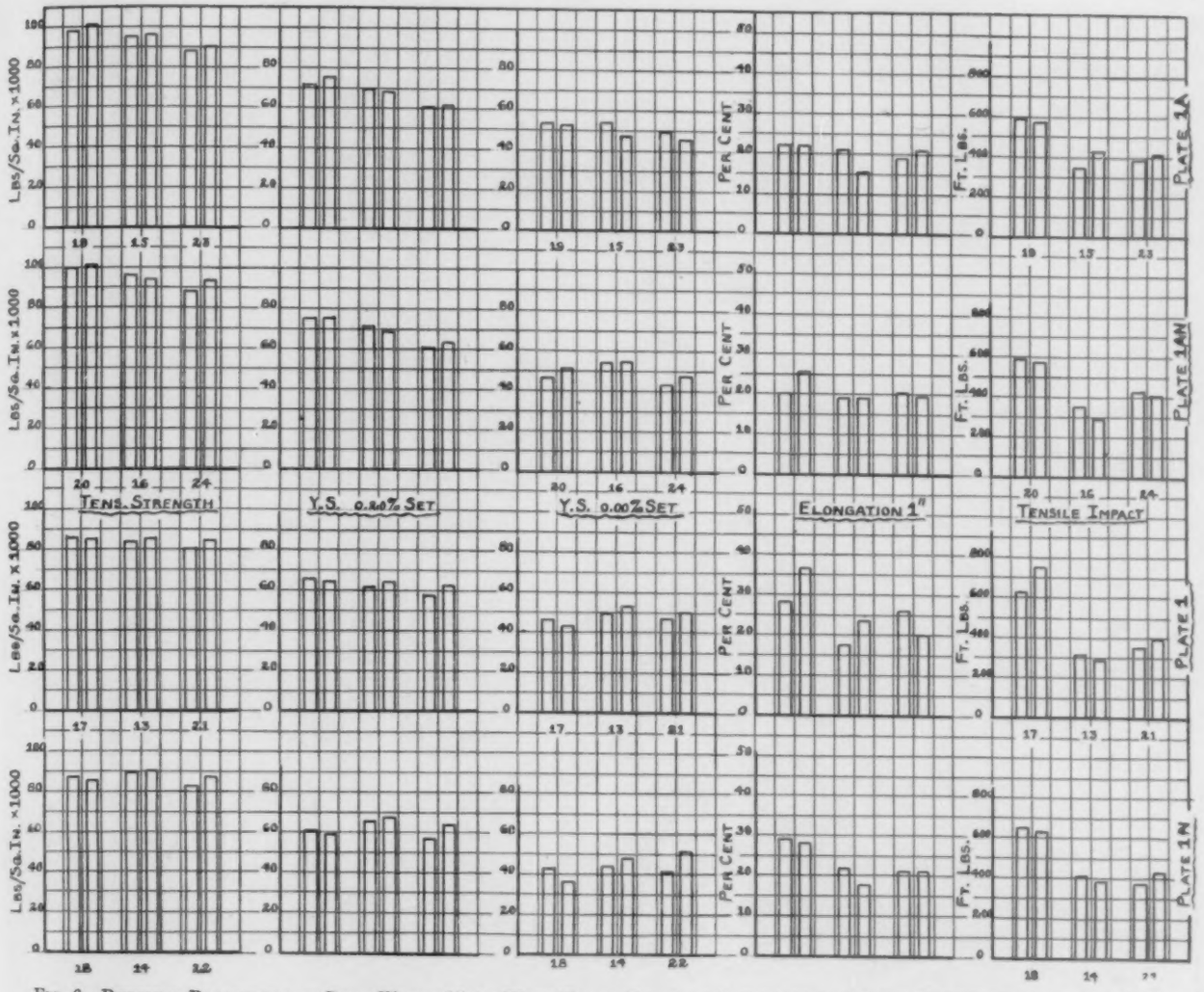

FIG. 6 PHYSICAL PROPERTIES OF BUTT WELDS MADE WITH THREE TYPES OF ELECTRODES ON FOUR DIFFERENT 1/2-IN. CU-NI-MO STEEL PLATES

(Numbers 13, 14, 15, and 16 indicate Toncan metal electrode. Numbers 17, 18, 19, and 20 indicate 0.50-Mo steel electrode. Numbers 21, 22, 23, and 24 indicate low-carbon steel electrode.)

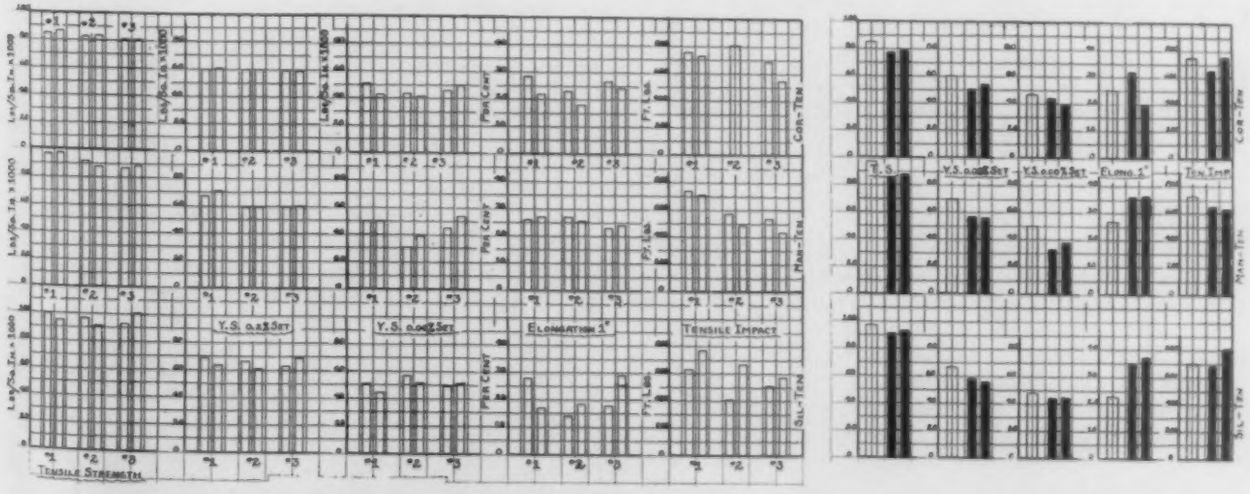

FIG. 7 PHYSICAL PROPERTIES OF BUTT WELDS MADE WITH THREE TYPES OF ELECTRODES ON 1/2-IN. ALLOY-STEEL PLATE

(Numbers 1, 2, and 3 indicate 0.50-Mo, 0.50-Mo, and low-carbon electrodes, respectively. Results shown by the right-hand group of graphs were obtained by using a 0.50-Mo electrode.)

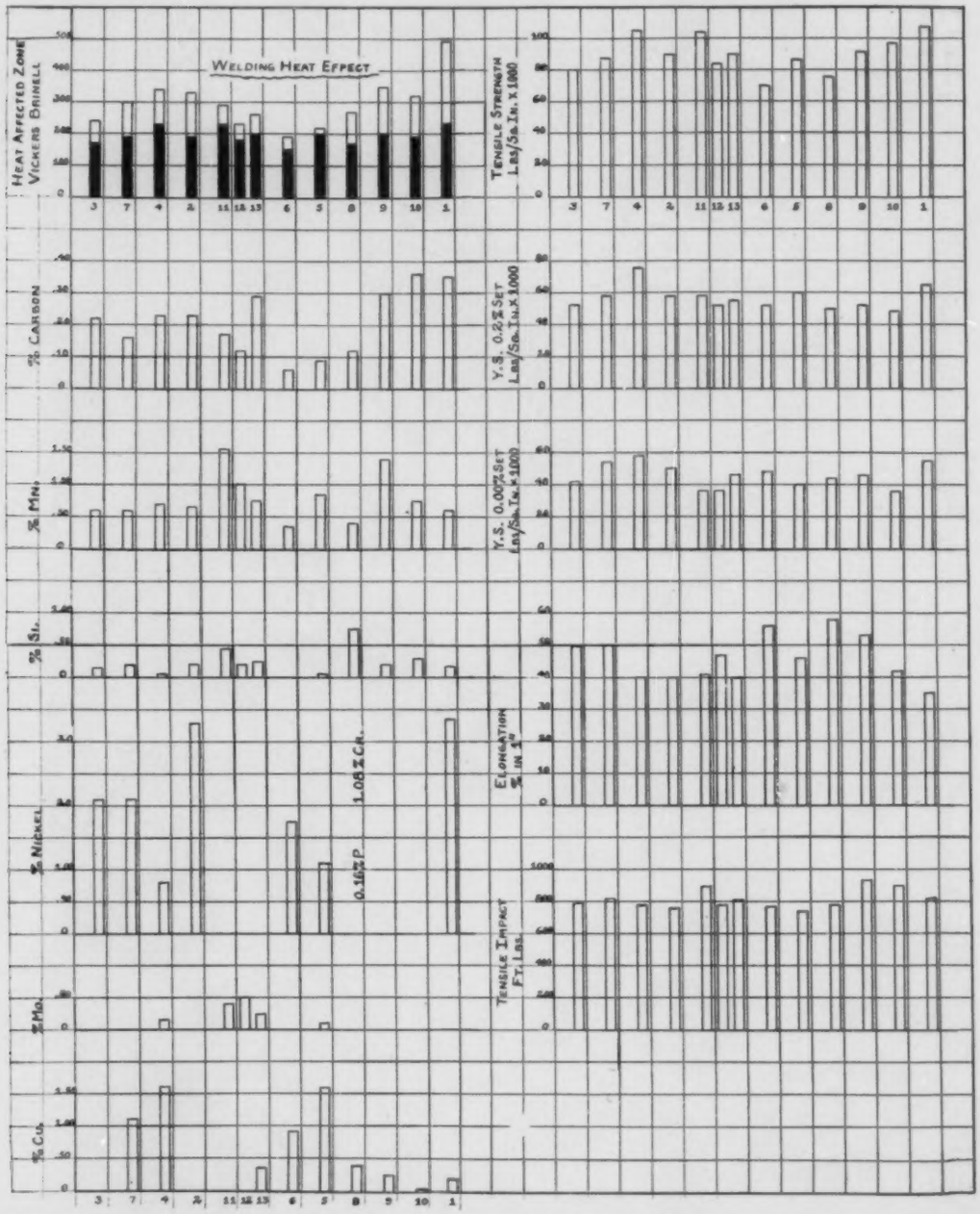

FIG. 8 LEFT: RELATION OF CHEMICAL COMPOSITION OF 1/2-IN. ALLOY PLATE AS ROLLED TO THE EFFECT OF WELDING HEAT. RIGHT: PHYSICAL PROPERTIES OF THE PLATE AS ROLLED

slow arc-travel speed of 4 to 6 in. per min, which is the approximate normal speed for hand welding. The shaded portion of each block represents the plate hardness unaffected by the heat of welding. The remainder of the left-hand column shows the amounts of the various alloying elements in the plate. The identification of the plates is shown at the bottom of the left-hand column. Physical properties of the plate as rolled are shown in the right-hand column.

It will be noted that the heat effect of welding varies nearly as much as the carbon content, and also that this variation is in no respect similar to the variation in content of any of the other elements shown. This point is believed significant as these data indicate that the heat effect of welding obtainable, as shown by the maximum hardness found, is determined mainly by the carbon content of the plate metal. The presence of metallic elements may affect the hardness value to some extent, but the effect of the carbon is of most importance. If a so-called weldable alloy steel is desired, the carbon content should be limited to a safe value which the author suggests as 0.25 per cent.

It is, of course, possible to weld a high-carbon steel or high-alloy steel by using special precautions and procedure, but by the term "weldable," the author understands that such a steel is to be capable of practical welding, easily and without the necessity for preheating or other heating or cooling precautions to avoid cracking and excessive hardness in the heat-affected zone.

A summary of heat-effect data on structural nickel-steel plate is shown in Fig. 9. The carbon content varies from approximately 0.20 to 0.45 per cent with a 2 and a 3 1/2 per cent nickel

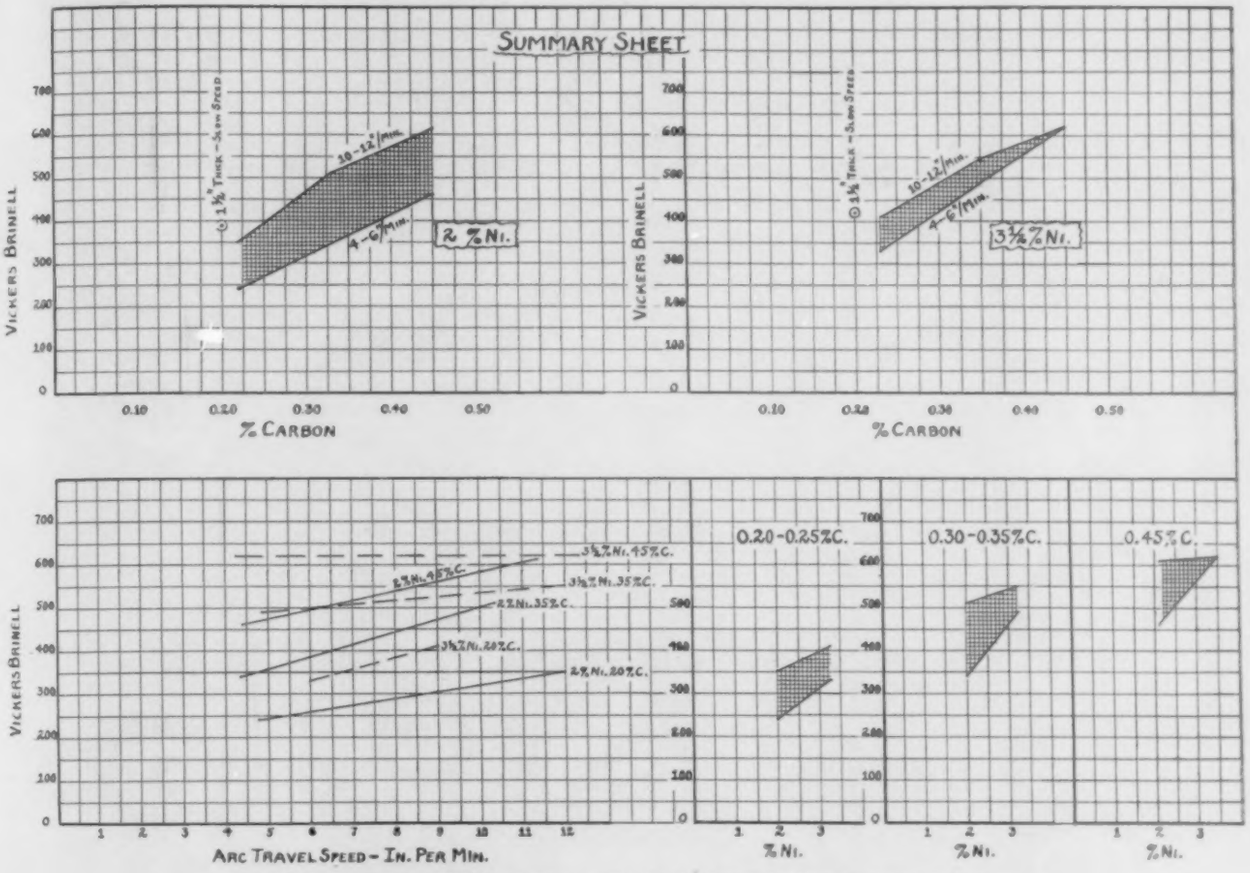

FIG. 9 EFFECT OF WELDING HEAT ON ½-IN. STRUCTURAL NICKEL-STEEL PLATE
(Courtesy of the International Nickel Company.)

content, respectively. These data show the pronounced effect of the carbon on the hardness of the heat-affected zone.

Nickel is sometimes considered as a hardening element in steel and should therefore be very limited in amount for weldability. A study of the data in Fig. 9 will show that when the carbon content is less than 0.25 per cent, the hardness in the heat-affected zone is not seriously affected by the nickel content. Also, if the averages of the shaded areas in the upper half of Fig. 9 were considered, it would be found that for 2 and 3½ per cent nickel content, the average hardness would be 430 and 500, respectively. Thus, for a 75 per cent increase of nickel, the average hardness increases about 15 per cent. If now we consider the 2 per cent nickel alone and compare the average hardness for the minimum and maximum carbon content, it is seen that for carbon contents of 0.22 and 0.45 per cent, the average hardness is 300 and 540, respectively. Thus, for a 100 per cent increase in carbon content there is an 80 per cent increase in the hardness of the heat-affected zone when 2 per cent of nickel is present. The same comparison when 3½ per cent nickel is present shows that with 0.22 and 0.45 per cent carbon, the average hardness is 370 and 600, respectively, or an increase of 65 per cent in the hardness of the heat-affected zone with a carbon increase of 100 per cent. These figures clearly indicate that the carbon content, rather than nickel, is of primary importance when considering the weldability of structural nickel steel.

It is regretted that the author has not sufficient data on steels containing other metallic elements as a major item along with carbon so that a similar comparison can be made. Data of this sort are of great importance not only to the designer of welded structures and the welding engineer who is concerned with the building of them, but also to the steel maker who must make steel plate suited to the requirements of the users of welded structures.

If we may assume, for the sake of argument, that the maximum hardness of the heat-affected zone is an index of the weldability of the steel plate, i.e., the lower the hardness in the heat-affected zone, the better is the weldability of the steel, and plot the tensile properties of the plate against this hardness, then we may obtain some conception of the desirability of various plate compositions for different design requirements.

In Fig. 10 are shown the values given in Table 1 plotted against the maximum hardness in the heat-affected zones as given in Table 4. The graphs in each of the figures have been arranged in five groups according to carbon content. If we consider the tensile strength and proportional (elastic) limit values shown, it is apparent that with a carbon content of 0.30 per cent or over, an increase of strength cannot be obtained without a considerable increase in the hardness of the heat-affected zone or, in other words, decreased weldability.

With a carbon content up to 0.22 per cent, the average slope of the curves is less than for carbon contents of 0.30 and 0.35 per cent, so that an increase of tensile strength or proportional (elastic) limit can be obtained with the lower carbon alloys at a much smaller sacrifice of weldability. This appears to the author as a fundamental metallurgical principle applicable to the welding qualities of structural alloy steels, the only difficulty being that in this study there are too few compositions in any one group.

If, therefore, this welding principle is true, then increased

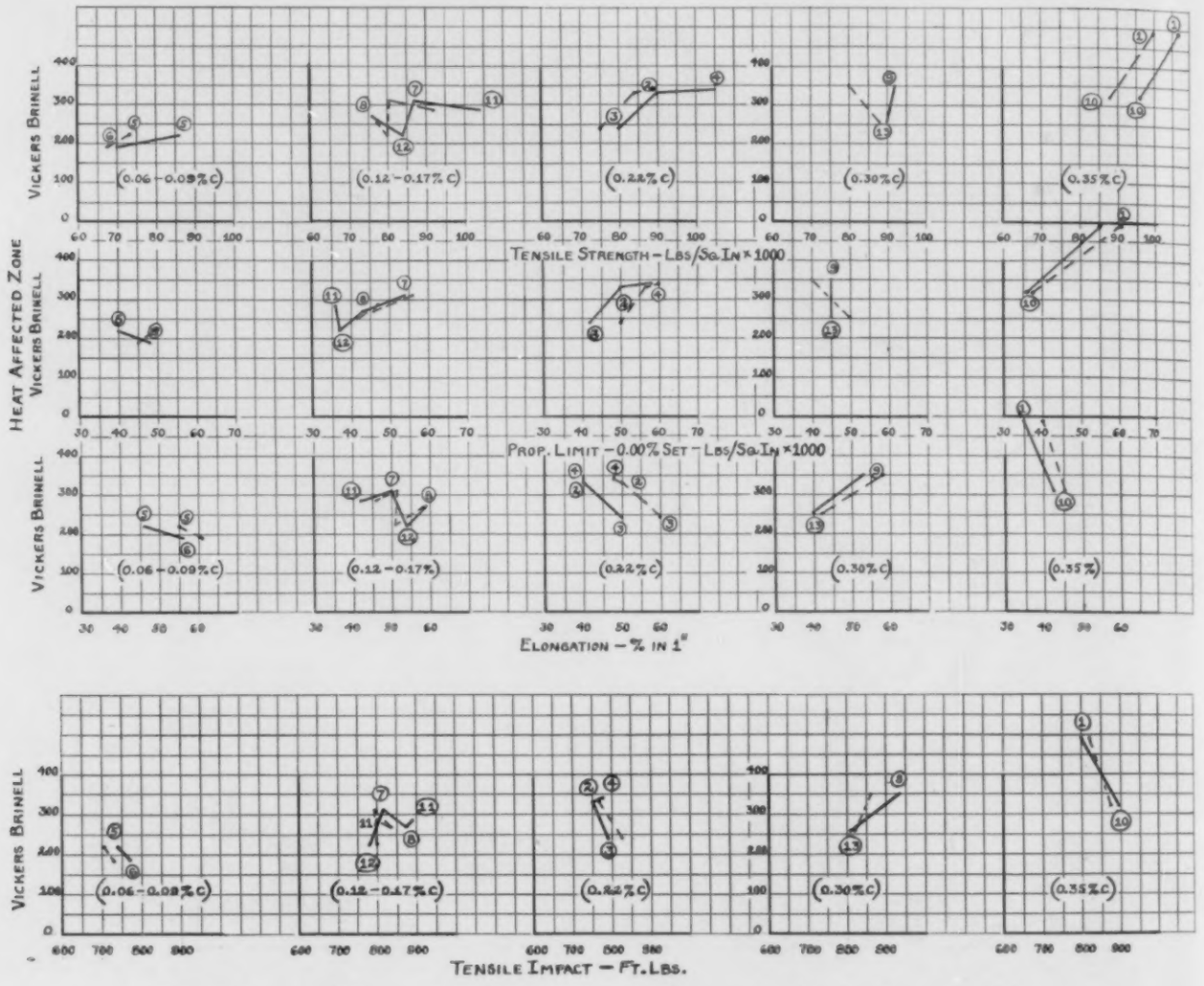
VICKERS BRINELL
HEAT AFFECTED ZONE VICKERS BRINELL
TENSILE STRENGTH – LBS/SQ. IN × 1000
PROP. LIMIT – 0.00% SET – LBS/SQ. IN × 1000
ELONGATION – % IN 1"
TENSILE IMPACT – FT. LBS.
(0.06 – 0.09% C)
(0.12 – 0.17% C)
(0.22% C)
(0.30% C)
(0.35% C)

FIG. 10 EFFECT OF WELDING HEAT VS. THE PHYSICAL PROPERTIES OF 1/2-IN. LOW-ALLOY-STEEL PLATE
(Numbers in circles refer to Table 1. Solid line indicates results from steels as rolled. The broken lines indicate results after stress relieving at 600 C.)

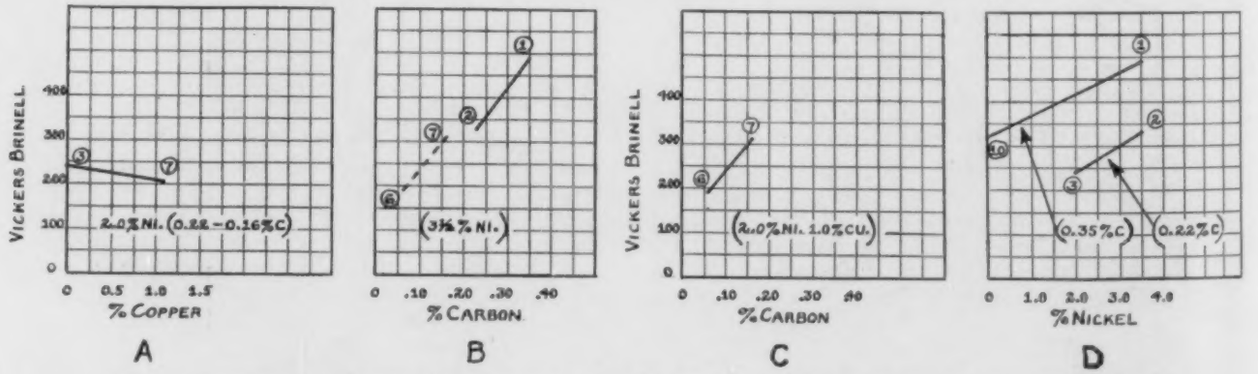

FIG. 11 INFLUENCE OF CHEMICAL COMPOSITION OF 1/2-IN. LOW-ALLOY-STEEL PLATE ON WELDING-HEAT EFFECT

tensile properties should be obtained, not by increasing the carbon content, but rather by increasing the alloy content of the steel and at all times the carbon should not be over 0.25 per cent for good weldability.

With reference to Fig. 10, the values for elongation and tensile impact appear to increase as the value for heat effect decreases, or weldability increases. This is as it should be. However, there is one exception to this rule, steel No. 9, which is in the range of 0.30 per cent carbon, shows an increase of these two properties with an increase of hardness or decrease of weldability. This particular steel is of high manganese content and no definite reason can be suggested for this apparent peculiarity.

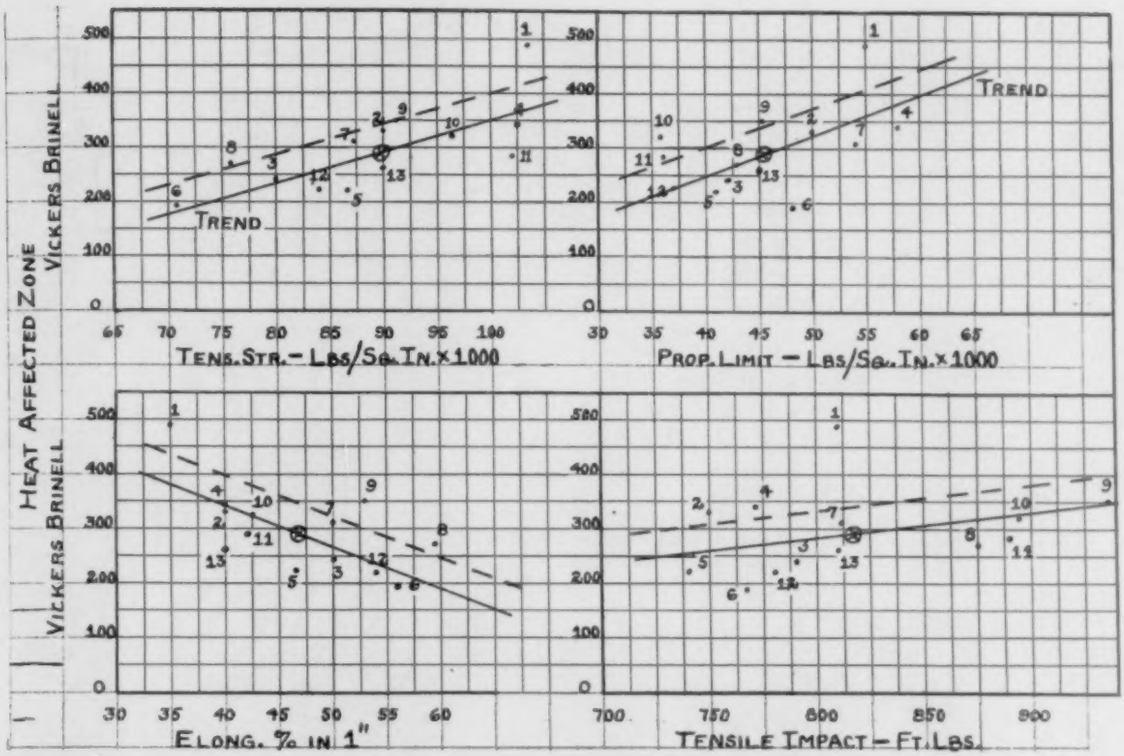

FIG. 12 EFFECT OF WELDING HEAT VS. THE PHYSICAL PROPERTIES OF 1/2-IN. LOW-ALLOY-STEEL PLATE AS ROLLED

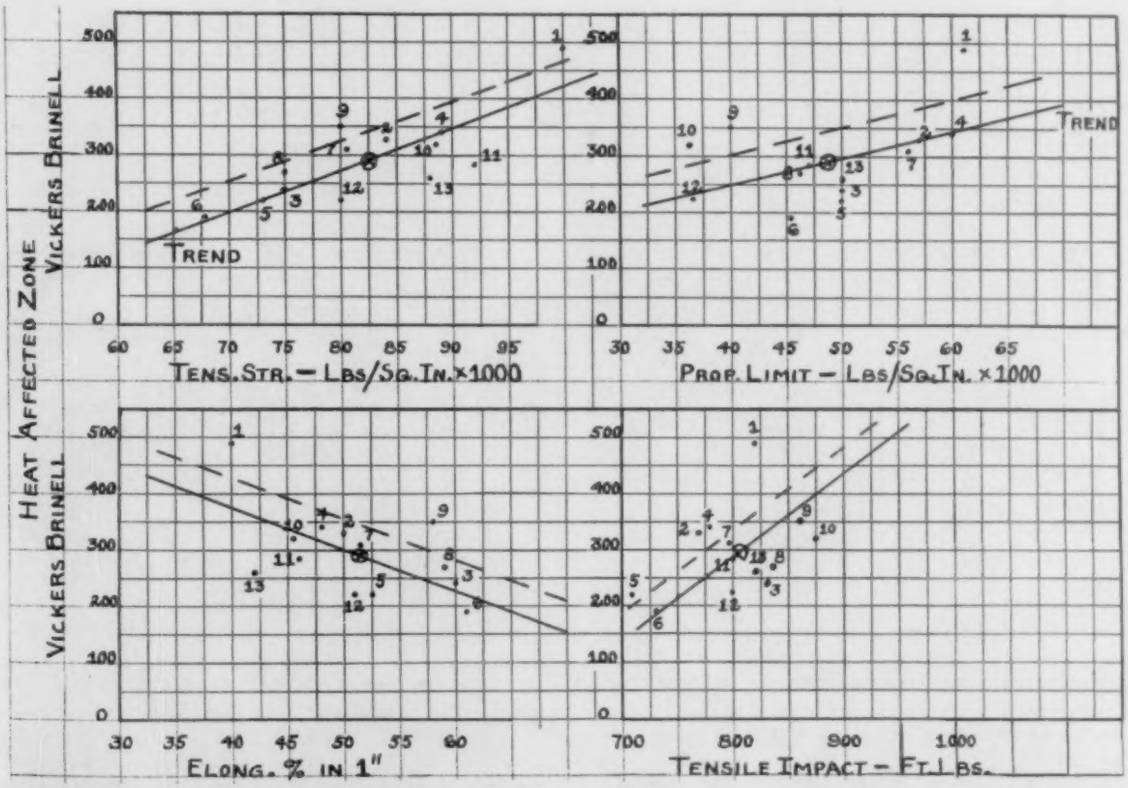

FIG. 13 EFFECT OF WELDING HEAT VS. THE PHYSICAL PROPERTIES OF 1/2-IN. LOW-ALLOY-STEEL PLATE AFTER STRESS RELIEVING AT 600 C

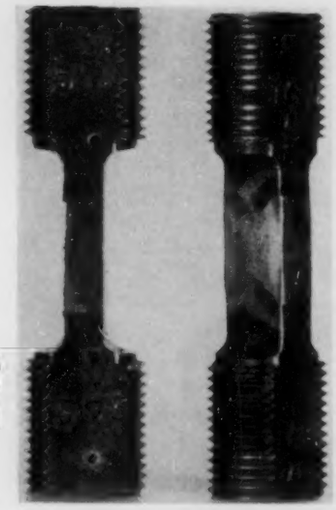

FIG. 14 LOW-TEMPERATURE TENSILE IMPACT-TEST SPECIMEN FOR BUTT-WELDS

In Fig. 11 are shown a few apparent relations between alloy content and heat effect of welding. The effect of copper indicates a decrease in hardness with an increase of copper in the presence of 2 per cent nickel. In this particular case, however, the carbon content also dropped from 0.22 to 0.16 per cent, so that the curve does not show the effect of the copper alone.

The effect of the carbon is shown in Fig. 11*B* and *C*. Note that the slope of the curves is slightly greater than 45 deg, which indicates a rapid increase of hardness with increasing carbon. Note here that the slopes of the two curves are practically identical, indicating that the effect of the carbon on the weldability is independent of the metallics present in the steel in this case.

Further, if we transpose the curve in Fig. 11*C* to the coordinates of Fig. 11*B*, it is seen that probably the steel containing 1.0 per cent copper, were the carbon to be increased to about 0.30 per cent, would have a slightly greater hardness than the 3½ per cent nickel steel. In this comparison about 1½ per cent of nickel is replaced by 1.0 per cent of copper with a resultant apparent greater hardness. However, it is possible that alloying elements in combination with each other have quite different effects than when acting alone in the steel. In any case, the effect of the carbon is self-evident.

By plotting the tensile properties of these steels together on one set of coordinates as shown in Figs. 12 and 13, the steels may be more easily compared. The average values, represented by the solid line, indicate a gradual increase of strength as the hardness of the heat-affected zone increases. If a maximum hardness of 50 points in excess of the average is allowed, then the broken line indicates an arbitrarily selected upper limit of acceptability for welding purposes.

Considering this method of testing only, these materials might be listed in the order of desirability shown by Table 5. It should

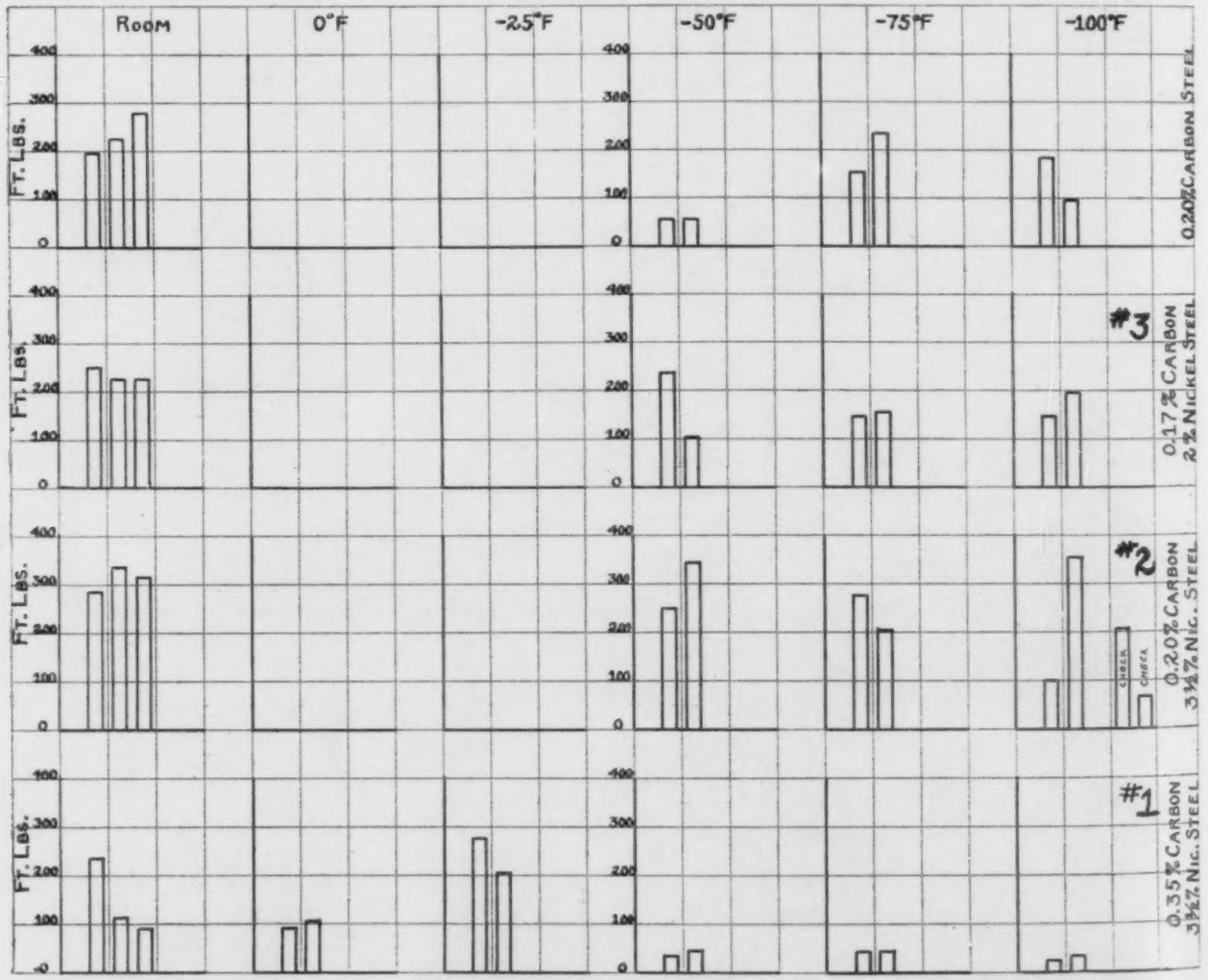

FIG. 15 RESULTS OF LOW-TEMPERATURE TENSILE IMPACT TESTS ON BUTT WELDS ON ½-IN. PLAIN-CARBON AND STRUCTURAL NICKEL-STEEL PLATE STRESS RELIEVED AT 600 C

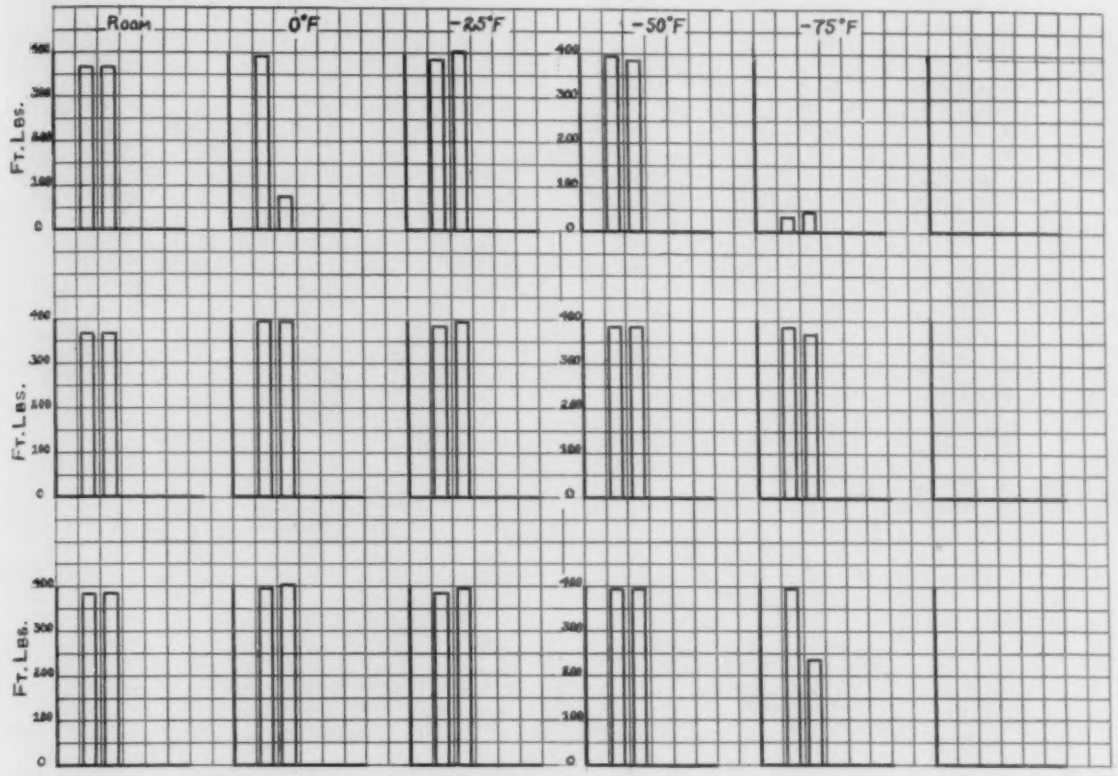

FIG. 16 RESULTS OF LOW-TEMPERATURE TENSILE IMPACT TESTS OF UNWELDED 1/2-IN. STRUCTURAL ALLOY-STEEL PLATE STRESS RELIEVED AT 600 C

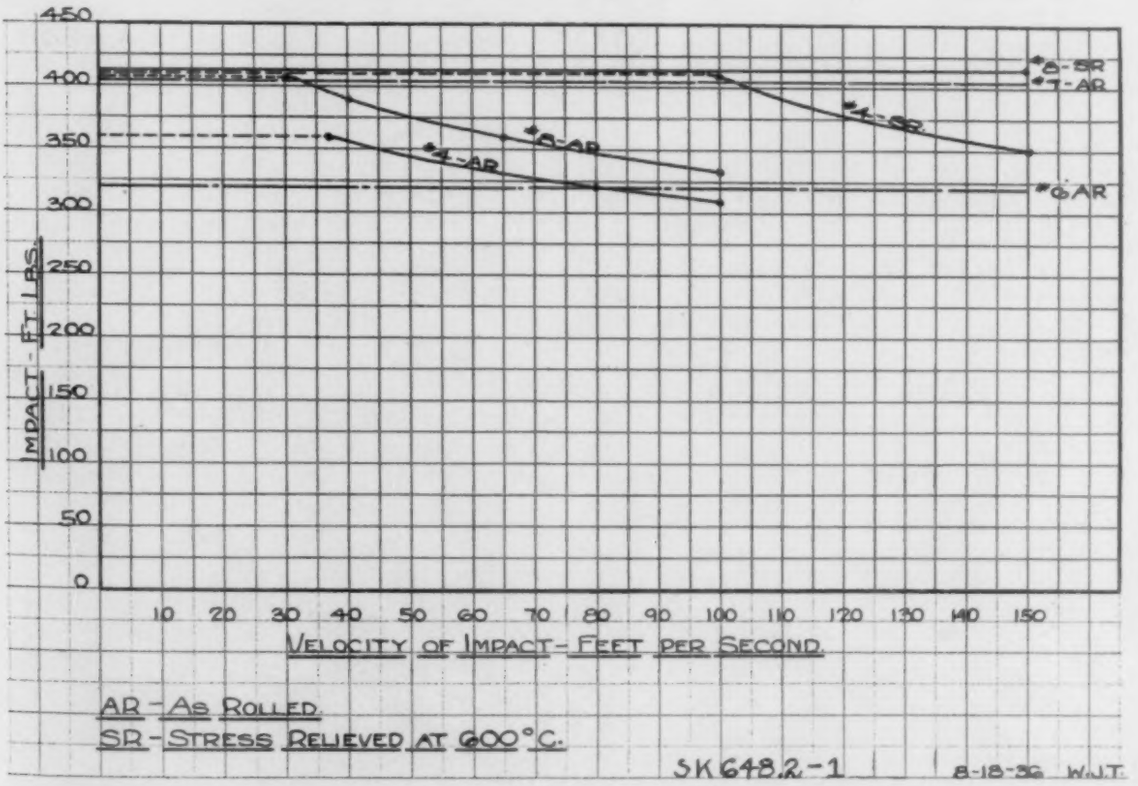

FIG. 17 RESULTS OF HIGH-VELOCITY TENSILE IMPACT TESTS OF UNWELDED 1/2-IN. STRUCTURAL ALLOY-STEEL PLATE
(Numbers on curves refer to steels listed in Table 1.)

TABLE TENTATIVE ORDER OF ACCEPTABILITY OF STEELS FOR WELDING PURPOSES

Strength of plate	Plate number[a] As rolled	Plate number[a] Stress relieved
Tensile strength, lb per sq in.:		
95,000 and over	11	1
	4	..
	10	..
	1	..
85,000 to 95,000	10	11
	13	10
	2	4
	9	13
	5	..
	7	..
75,000 to 85,000	5	12
	12	2
	7	7
	3	9
	8	..
60,000 to 75,000	6	3
	8	8
	..	5
	..	6
Proportional (elastic) limit, lb per sq in.:		
55,000 and over	4	4
	1	2
	..	1
	..	7
45,000 to 55,000	7	7
	2	5
	6	3
	1	13
	9	11
	..	8
40,000 to 45,000	13	6
	8	8
	3	..
	9	..
	5	..
35,000 to 40,000	3	12
	5	9
	12	10
	11	..
	10	..

[a] Numbers refer to Tables 1 and 2.

be understood, however, that these data cover only the phases of weldability discussed here and, that other factors not studied here may change the desirability of any given composition of steel for a given welded structure.

The specified minimum tensile-strength and yield-point requirements for steel plate used in welded ordnance structures are 85,000 and 50,000 lb per sq in., respectively. These limits allow steels Nos. 11, 1, 13, 10, and 4 to be considered for tensile strength in the stress-relieved condition, while steels Nos. 4, 1 2, and 7 can be considered for elastic limit in the stress-relieved condition. Steels Nos. 5–3–13 are on the line at an elastic limit of 50,000 lb per sq in., but this is too close to the minimum to be considered.

This leaves steel No. 1, as second choice in both cases because of the high hardness in the heat-affected zone. Steel No. 11 is best for tensile strength and steel No. 4 is best for elastic strength and both are of considerably lower carbon content than steel No. 1, which makes for lower hardness in the heat-affected zone, or better weldability, although steel No. 11 falls below the limit on elastic strength. Steel No. 2 (0.22 per cent carbon and 3.5 per cent nickel) is very acceptable on elastic strength but falls down below the limit of 85,000 lb per sq in. tensile strength, and its weldability (heat effect) is on a par with steel No. 4, which with steel No. 1 is included in both groups.

It is hoped that eventually a similar study may be made of weld properties on these steels when the welding tests have been completed. Under those conditions comparisons may be somewhat complicated by differences in electrode materials.

The tensile properties of steels as normally determined present a relationship between certain characteristics of the materials which may change considerably under other types of tests, such as low-temperature impact and high-velocity impact.

In Fig. 14 is shown the shape of test specimen used at the Watertown arsenal for low-temperature impact tests of butt welds. The specimen shown is used for $^1/_2$-in. thick plate and has a straight test section 1 in. long with $^1/_2$-in. radius at each end, or a total length between shoulders of 1.25 in. The cross section is $^1/_4$ in. wide by the plate thickness, and the total length of the specimen is approximately 3 in. Tests of the unwelded plate are made also with this specimen.

Low-temperature impact data on butt welds of $^1/_2$-in. structural carbon-steel and structural nickel-steel plate are shown in Fig. 15. The No. 2, 0.20 C-3.5 Ni steel holds up best at low temperature, and the effect of the carbon on the subzero impact strength is clearly indicated by comparing the results for steels Nos. 1 and 2. The structural carbon-steel plate shows a decided drop at —50 F.

Low-temperature impact data on plates Nos. 8, 9, and 10 listed in Table 1 are shown in Fig. 16. The test specimen used was that shown in Fig. 14. Steel 9, containing high manganese with medium carbon, appears to hold up better at low temperature under impact loads than either No. 8 or No. 10.

In Fig. 17 are shown data on four structural alloy steels tested in the variable-speed impact testing machine at the Watertown arsenal laboratory. The data shown indicate that there is no drop in the impact strength of the copper-nickel steel in the as-rolled condition up to 150 fps velocity of impact. The high-phosphorus steel shows no drop up to this velocity in the stress-relieved condition but as-rolled this steel does show a drop at a velocity of about 30 fps. These data indicate the value of stress relieving.

Steel No. 4, also included in Fig. 17, shows not only an increase of critical velocity on stress relieving but also an increase of impact strength of approximately 15 per cent.

At the time this paper was prepared these tests were not completed but it is hoped that eventually the data on low-temperature impact and high-velocity impact will become available not only on the plate materials themselves, but also on butt welds of these materials made with various electrodes. With data of this kind available, it is quite probable that the comparison of weldability may be somewhat different from that derived by the tensile test alone.

It is of interest to consider, for a moment, the possibilities offered for comparing structural steels by the tests mentioned in this discussion. The tensile test gives values which the designer can use for design of structures for static loads. The tensile impact test[3] either at room or low temperatures does not give values which the designer can apply directly to his design, but the results of such tests are a valuable guide to the selection of material for the design where dynamic loading is to be encountered.

In conclusion, the author wishes to acknowledge the invaluable assistance and many helpful suggestions of Colonel G. F. Jenks, Commanding Officer, Watertown arsenal, and Chairman, Subcommittee on Industrial Research, Engineering Foundation. The help given by the International Nickel Company, and the Climax Molybdenum Company, and the privilege of using data obtained under their sponsorship is appreciated. The samples of plate material furnished by the Carnegie Steel Company, the Republic Steel Corporation, and the Youngstown Sheet and Tube Company have greatly facilitated this study of the welding quality of low-alloy steels.

[3] "The Relation Between the Tension Static and Dynamic Tests," by H. C. Mann, Proceedings A.S.T.M., vol. 35, part 2, 1935, pp. 323–335.

A List of Fundamental Research Problems in Welding and Reviews of Recent Welding Literature

Compiled by the Fundamental Research Subcommittee of

The Welding Research Committee of the Engineering Foundation Sponsored Jointly by the American Welding Society and the American Institute of Electrical Engineers

INDEX

		PAGE
	ORGANIZATION OF WELDING RESEARCH	1
	ALPHABETICAL LIST OF RESEARCHERS	2
	TABULATED GROUPING OF RESEARCHERS	4
	LIST OF FUNDAMENTAL RESEARCH PROBLEMS IN WELDING	4
	Group A—Tests of Mechanical Properties	5
	Group B—Metallurgical	6
	Group C—Physics	7
	Group D—Welding Procedure	8
	Group E—Structural Studies	8
	Group F—Chemistry	9
	Group G—Personnel	9
	APPENDICES (REVIEWS OF RECENT WELDING LITERATURE)	
I.	Effect of Carbon on the Properties of Fusion Welds in Steel	9
II.	Effect of Silicon on the Fusion Welding of Steel	11
III.	Effect of Manganese on the Properties of Fusion Welds in Steel	12
IV.	Welding Alloy Steels	14
	A—Low-Alloy Steels	
	B—Stainless and Related Alloy Steels	
	C—Alloy Steels discussed at the British Welding Symposium	
	D—The Modulus of Elasticity of Austenitic Welds in Mild Steel	
V.	Welding Non-Ferrous Metals (Excluding Copper)	19
	A—General and Nickel	
	B—Zinc and Lead	
	C—Aluminum (General)	
	D—Aluminum (Process)	
	E—Aluminum (Alloys and Castings)	
VI.	Welding Cast Iron	25
VII.	Resistance Welding Electrodes	26
VIII.	Metal Transfer in Welding and Allied Topics	27
	A—Metal Transfer in the Arc	
	B—Magnetic Blow and Generator Characteristics	
	C—Physics of the Arc	
	D—Gas	
IX.	X-ray Weld Testing	31
X.	Weld Shrinkage	33
	A—Theoretical and Experimental	
	B—Shrinkage from the Field Standpoint	
	C—Shrinkage discussed at the British Welding Symposium	
XI.	Stress Distribution in Welded Joints	38
XII.	Corrosion of Welds	39

NOTE: The superior numbers throughout the texts refer to the bibliography which is appended to each section. The appendices summarize literature from Jan. 1935 to Sept. 1936. Some 1934 references have been included in some of the reviews.

IN THE year 1935 the Engineering Foundation appointed a Welding Research Committee and launched the project by an initial grant which has been supplemented by financial contributions from industry.

Fundamental Researches

With the growing use of welding there is a greater need than ever before for investigations of the fundamentals. The "reason why" of things is rarely understood and none too often sought. Again, in other instances there is a lack of fundamental design data. To meet the present needs and foster researches of this kind, a Subcommittee on Fundamental Research was appointed under the chairmanship of Mr. H. M. Hobart. For brevity this body may be called the Fundamental Research Committee. This committee continues the numerous activities initiated several years ago by the same chairman during affiliation of this committee with the AMERICAN WELDING SOCIETY. The opportunities for real service to the industry in this work are almost limitless and the possibilities of securing results of value are extremely great. Some of these problems can be best handled by the university. Moreover, in this way the teaching staff and students will become familiar with the recent developments in welding practice.

Applied Investigations

Simultaneously, a Subcommittee on Industrial Research has been organized under the chairmanship of Colonel G. F. Jenks, Commanding Officer, Watertown Arsenal, Watertown, Massachusetts. The closest cooperation between these subcommittees will prevail and in many instances investigations sponsored by the Industrial Research Committee will be conducted in universities or governmental departments, as may seem desirable.

Literature

In order to make available the knowledge existing in the literature, a third subcommittee has been appointed under the chairmanship of J. H. Critchett, Vice-President, Union Carbide and Carbon Research Laboratories, which will endeavor to summarize in usable form the available knowledge scattered in hundreds of journals and in many foreign languages. Here, again, the Fundamental Research Committee will cooperate, and, in many instances, members of the committee will be called upon to assist in making specialized reviews in the fields in which they are experts.

The Fundamental Research Committee comprises representative scientists of industry and also professors interested in the conduct of fundamental research work in welding. In particular, the Committee endeavors to stimulate interest in these investigations on the part of various universities. A list of problems needing investigation is compiled each year and distributed to selected universities. These universities are allowed a free hand in the selection of problems for study. The Committee assists, when called upon, in the formulation of problems undertaken for study.

Local Branches of the Committee

To expedite progress and to hold more frequent meetings of local groups interested in fundamental research in welding, and to promote more active cooperation of local industries, branches of the Fundamental Research Committee have been formed in Boston, P. J. Horgan, Lynn Works, General Electric Company Hemenway R. Bullock, Massachusetts Institute of Technology, *Chairman;* New York, C. W. Obert, Union Carbide and Carbon Company, *Chairman;* Pittsburgh, C. H. Jennings, Westinghouse Electric & Manufacturing Company, *Chairman;* Northern New York, A. Vogel, General Electric Company, *Chairman;* Pacific Southwest, N. F. Ward, University of California, *Chairman;* Chicago, Jules Muller, Chicago Steel & Wire Company, *Chairman.*

Alphabetical List of Researchers, Their Affiliations and Their Subjects. (As Revised Nov. 1936)

Research Being Conducted by	Affiliation	Name of Chairman of Regional Section	Subject of Research
1. Prof. Edward Bennett	Univ. of Wisconsin	J. Muller	Studies Relating to the Selective Heating of Large Conducting Bodies in Strips by Utilizing the "Proximity Effect" to Control the Distribution of Heating Currents of the Audio Frequency Range
2. Prof. H. Beresford	Univ. of Idaho, Agricultural Engg. Dept.		Application of Wear Resistant Surfaces to Agricultural Equipment and Tools.
3. Prof. H. M. Boylston	Case School of Applied Science, Dept. of Metallurgy	C. H. Jennings	(*a*) Metallurgical Investigations on Welds (*b*) Factors Influencing the Welding Quality of Steel
4. H. R. Bullock	Mass. Inst. Technology	P. Horgan	Study of Oxy-Acetylene Cutting
5. Prof. F. Creedy	Univ. British Columbia		(*a*) Characteristics of the Copper Arc, between Revolving Electrodes (*b*) Physics of the Arc (*c*) Characteristics Required for Steady Welding (*d*) Characteristics of Welding Apparatus (i.e., in Arc Welding)
6. J. J. Crowe	Air Reduction Co.	C. W. Obert	Cutting
7. Prof. H. L. Daasch	Iowa State College Dept. of Mech. Engg.		
8. Prof. R. P. Davis	West Virginia Univ.		Inactive at Present
9. Prof. A. V. deForest	Mass. Inst. Technology, Mech. Engg. Dept.	P. Horgan	Vibration Studies of Welded Structures
10. Prof. D. J. Demorest	Ohio State Univ.	C. H. Jennings	Non-Destructive Tests for Welds by Magnetic Methods, X-Ray and Radium Ray
11. Prof. J. P. DenHartog	Harvard Univ.	P. Horgan	Influence of the Welding Heat on the Structure of the Adjacent Metal
12. Prof. G. E. Doan	Lehigh Univ., Dept. of Physical Metallurgy		(*a*) A Study of Metal Transfer During Arc Welding (*b*) A Study of the Basic Nature of the Arc Discharge Under Conditions of High Purity (*c*) The Properties of Weld Metal Made with Pure Iron in Argon and Other Atmospheres (*d*) The Use of Gamma Rays for Weld Examination (*e*) Acceleration of Rate of Welding by Additions to the Welding Wire
13. A. S. Douglass	Detroit Edison Co.		Library Research on Temporary and Permanent Weld Stresses
14. Prof. S. L. Goodale	Univ. of Pittsburgh, Dept. of Metallurgy	C. H. Jennings	(*a*) Annealing of Welded Joints (*b*) Strain Annealing of Medium Carbon Steel (0.25 to 0.30%)
15. Prof. A. Haertlein	Harvard Univ.	P. Horgan	Analysis of Certain Structural Welding Problems
16. Prof. P. R. Hall	Penn. State College, Dept. of Industrial Engg.	C. H. Jennings	Welding of Cast Iron
17. Prof. O. M. Harrelson	Georgia School Tech., Mech. Engg. Dept.		The Effect of Controlling Welding Procedure and Peening on the Physical Properties and Transition Constituents of the Material

18.	W. A. Harvey	J. A. Roebling's Sons Co.		Corrosion Fatigue Testing
19.	Prof. O. H. Henry	Polytech. Inst. of Bklyn. Dept. of Mech. Engg.	C. W. Obert	Effect of Low Temperature on the Static and Dynamic Tensile Strength of Welded Joints in Some Ferrous and Nonferrous Metals; Fatigue Tests of Welded Joints at Low Temperatures
20.	Prof. W. F. Hess	Rensselaer Polytech. Inst. Dept. of Elec. Engg. and Physics	A. Vogel	(*a*) Ignition of Alternating Current Arcs (*b*) Impact Studies of Fillet Welds
21.	Prof. N. S. Hibshman	Lehigh Univ.		Under Water Welding
22.	Prof. A. P. Hoelscher	Purdue Univ.		
23.	Prof. S. C. Hollister	Cornell Univ.	A. Vogel	Locked-Up Stresses in Welds; Repeated Stress in Welded Connections
24.	Prof. T. P. Hughes and H. R. Chhabra Prof. T. P. Hughes and E. Nelson	Univ. of Minnesota, Dept. of Mech. Engg.	J. Muller	Relation of Current and Voltage to Speed of Welding Ductility Values as Obtained by the Tensile and Cold-Bend Tests
25.	Prof. R. E. Jamieson	McGill Univ. Montreal, Dept. of Civil Engg.,	A. Vogel	Initial Stress Caused by Welding
26.	C. H. Jennings	Westinghouse E. & M. Co., Pittsburgh	C. H. Jennings	Strength and Design of Welded Joints
27.	C. D. Jensen	Lehigh Univ., Civil Engg. Dept.		Under-Water Welding. Effect of Temperature of Atmosphere on Welding of Structural Alloy Steels. Effect of Speed of Loading on Ultimate Strength of Welds in Tension, Bending and Shear. Strength and Design of Welded Joints
28.	Prof. W. B. Kouwenhoven	Johns Hopkins Univ.		(*a*) Flux Penetration Tests (*b*) Non-Destructive Tests for Welds
29.	Prof. W. J. Krefeld	Columbia Univ., Dept. of Civil Engg.	C. W. Obert	Inactive at present
30.	Prof. T. R. Lawson	Rensselaer Polytech., Inst. Head, Dept. Civil Engg.	A. Vogel	(*a*) Quantitative Studies of the Stresses Caused by Welding Operations (*b*) Photoelastic Studies of Stresses in Riveted and in Welded Joints (*c*) Impact Stresses in Welded Joints
31.	Dr. H. H. Lester	Watertown Arsenal	P. J. Horgan	X-Ray Specifications for Castings and Welded Structures
32.	Prof. Inge Lyse	Fritz Engg. Lab., Lehigh Univ.		(*a*) Photoelastic Studies of Bending in Welded Joints (*b*) Rigidity of Welded Structural Connection (*c*) All-Welded Vierendeel Trusses
33.	F. S. Mapes and F. Howenstein	Schenectady Wks. Lab., General Electric Co.	A. Vogel	Inactive at present
34.	Prof. H. J. Masson	New York Univ. Dept. of Chemical Engg.,	C. W. Obert	Corrosion Fatigue Tests of Welded Joints
35.	Prof. F. O. McMillan, Prof. S. H. Graf and W. H. Horning	Oregon State Agric. College		The Magnetic Blow of the Electric Arc Flame
36.	Dr. D. W. Murphy	Univ. Michigan, Dept. of Engg. Research		Determination of Oxygen and Nitrogen Content
37.	Dean J. A. Needy	Ohio Northern Univ., College of Engg.	C. H. Jennings	Problems in the Welding of Cast Iron
38.	Prof. J. T. Norton	Mass. Inst. Tech., Dept. of Mining & Metallurgy	P. J. Horgan	(*a*) Radiographic Technique of Examining Welds (*b*) X-Ray Diffraction Method for Investigating Stresses in Welds (*c*) X-Ray Studies of Age-Hardening
39.	Prof. O. D. Rickly	Ohio State Univ., Dept. of Industrial Engg.	C. H. Jennings	Study of Residual Stresses in Welded Joints Shear and Impact Tests of Welds
40.	Prof. M. F. Sayre	Union Coll., Dept. of Civil Engg.	A. Vogel	Development of Methods of Testing Welds
41.	Prof. G. S. Schaller	Univ. Washington, Dept. of Mech. Engg.		(*a*) Development of an Arc with a Gaseous Atmosphere (*b*) Oxy-Acetylene Welding of Cast Iron
42.	Prof. R. R. Seeber and A. P. Young	Mich. Coll. Mining & Tech., Dept. of Mech. Engg.		(*a*) Copper Welding (*b*) Method of Testing Welds
43.	Prof. A. H. Sluss and V. M. Smith	Univ. of Kansas		Fatigue Testing of Fusion Welded Butt Joints
44.	A. Solakian	Columbia Univ.	C. W. Obert	Photoelastic Studies
45.	W. Spraragen and Dr. G. E. Claussen	Welding Research Com.	C. W. Obert	Resistance of Welded Joints to Fatigue
46.	Prof. J. G. Tarboux	Univ. of Tennessee		Magnetic Field Intensities Surrounding Arcs
47.	Dr. E. Therkelsen	Montana State Coll., Dept. of Mech. Engg.		Inactive at Present
48.	R. H. Thielemann	Oregon State Agric. Coll.		A Photoelastic Analysis of Ladle Hook Design Theory
49.	Prof. L. Thomassen	Univ. Mich., Dept. of Chemical Engg.	A. S. Douglass	Oxidation of Welds in Alloy Steels
50.	Prof. G. E. Thornton	State Coll. Washington, Dept. of Mech. Engg.		Fatigue Tests
51.	A. Vogel	Schenectady Wks., General Elec. Co.	A. Vogel	(*a*) Investigations of Forms of Impact Tests (*b*) Investigations of Forms of Shear Tests
52.	Prof. N. F. Ward	Univ. California, Dept. of Mech. Engg.	N. F. Ward	(*a*) Creep Tests of Gas Welds in Medium-Carbon Steel (*b*) Some Controlling Elements for Resistance Welding of Thin-Gauge Metals

				(*c*) Study of Resistance Drop During Resistance Welding of Thin-Gauge Metals of Low Resistivity Especially in Relation to Spacing of Welds for Uniform Strength
53.	W. L. Warner	Watertown Arsenal	P. J. Horgan	Arc Welding of High Tensile, Low-Alloy Steels
54.	Prof. A. E. White, Dr. C. L. Clark and R. Schneidewind	Univ. of Michigan	A. S. Douglass	(*a*) Creep of Metals and Welded Structures at High Temperatures (*b*) Resistance to Oxidation, Embrittlement and Fatigue
55.	Prof. W. M. Wilson	Univ. of Illinois, Dept. of Civil Engg.	Jules Muller	
56.	S. F. Yasines	New York Univ.	C. W. Obert	Structural Welding
57.	Dr. M. Yatsevitch	Watertown Arsenal	P. J. Horgan	Coefficient of Expansion of Weld Metal

Library Research

Before a convincing attack can be made on many of the suggested research problems it is necessary to find out what is known about the particular question. Library research is the means of finding out what has been done by people whom we do not know. The Fundamental Research Committee is endeavoring in three ways to simplify the increasingly difficult task of library research. First, it will undertake searches of literature on restricted topics of immediate importance to welding research workers who have limited library facilities and time. Second, it is endeavoring to simplify library research in the future by procuring comprehensive critical reviews of assigned topics of the world's welding literature. Reviews of this sort summarize what is known, what is doubtful, and what topics remain unexplored. Third, the Committee is considering the possibility of securing periodical impartial reviews of current literature and progress on major topics, such as developments in equipment and methods. There is no question of the value of such reviews in hastening the adoption of new methods and materials, and in promoting confidence and progressive thought along welding lines.

Tabulated Grouping of Researchers with Respect to the Material and Functional Committees of the Subcommittee on Industrial Research

	Cast Iron	Carbon Steels	Low-Alloy Steels	High-Alloy Steels	Aluminum Alloys	Copper Alloys	Nickel Alloys	Methods of Testing	Analysis of Weld Failures	Weld Stresses—Causes and Effects
Prof. E. Bennett										x
Prof. H. Beresford										
Prof. H. M. Boylston		x	x	x						
H. R. Bullock										
Prof. F. Creedy						x				
J. J. Crowe		x								
H. L. Daasch										
Prof. R. P. Davis		x								
Prof. A. V. deForest								x		
Prof. D. J. Demorest								x		
Prof. J. P. DenHartog										x
Prof. G. E. Doan		x						x		
A. S. Douglass										x
Prof. S. L. Goodale		x	x							x
Prof. A. Haertlein		x								
Prof. P. R. Hall	x									
O. M. Harrelson										x
W. A. Harvey								x		
Prof. O. H. Henry				x				x		
Prof. W. Hess								x		
Prof. N. S. Hibshman										
Prof. A. P. Hoelscher										
Prof. S. C. Hollister								x		x
Prof. T. P. Hughes and H. R. Chhabra		x								
Prof. T. P. Hughes and E. Nelson									x	
Prof. R. E. Jamieson										x
C. H. Jennings		x								
Prof. C. D. Jensen									x	
Prof. W. B. Kouwenhoven									x	
Prof. W. J. Krefeld										
Prof. T. R. Lawson										x
Dr. H. H. Lester									x	
Prof. Inge Lyse									x	
F. S. Mapes and F. Howenstein									x	
Prof. H. J. Masson									x	
Prof. F. O. McMillan, Prof. S. H. Graf and W. H. Horning										
Dr. D. W. Murphy		x								
Dean J. A. Needy	x									
Prof. J. T. Norton		x	x						x	x
Prof. O. D. Rickly									x	x
Prof. M. F. Sayre									x	
Prof. G. S. Schaller	x									
Prof. R. R. Seeber and A. P. Young						x		x		
Prof. A. H. Sluss and V. M. Smith								x		
Prof. A. G. Solakian										x
W. Spraragen and Dr. G. E. Claussen								x		
Prof. J. G. Tarboux										
Dr. E. Therkelsen										
R. H. Thielemann										
Prof. L. Thomassen			x	x						
Prof. G. E. Thornton								x		
A. Vogel								x		
Prof. N. F. Ward									x	
W. L. Warner			x							
Prof. A. E. White, Dr. C. L. Clark and R. Schneidewind		x	x							
Prof. W. M. Wilson										
Prof. S. F. Yasines								x		
Dr. M. Yatsevitch		x								

List of Fundamental Research Problems in Welding

The Fundamental Research Committee has revised its list of research problems, originally prepared in 1932. Some of the problems suggested in the first list have been solved and struck off the revised list. Others, particularly the general problems, retain their importance and reappear in the revised list. Inevitably new problems have arisen in the interim between the preparation of the old list and the new, and these new problems form the bulk of the revised list. The Committee will greatly appreciate suggestions, opinions and comments from those interested in any of the problems of welding. These communications should be sent to Mr. W. Spraragen, Secretary of the Subcommittee on Fundamental Research, Welding Research Committee, 29 West 39th Street, New York, N. Y.

Group A—Tests of Mechanical Properties

It appears at first sight paradoxical that we have far more complete information about the physical and chemical properties of materials in the unjoined condition than in the joined. In the application of any engineering material some process of joining must be adopted, such as welding, riveting or soldering. Furthermore, the physical and chemical properties of the material upon which design is based are generally limited by the properties of the joint. These limitations are imposed by a number of factors:

1. Stress concentrations due to the shape of the joint and the reaction of the material to notch effects.
2. Shrinkage stresses arising from the joining process.
3. Heterogeneity of structure and composition of plate and added metal (weld metal or rivet) in the joint.
4. Workmanship.

The problem of the testing of joints is complicated by these factors, which probably accounts for the unattractiveness of the problem to the busy materials testing laboratory. It has also been argued that variables related to process, particularly in welding, are so numerous and the development of electrodes and materials is so rapid that test results quickly become out of date. If this is so, it may possibly explain the absence, even at the present day, of adequate information about the properties of riveted joints, although there has been no fundamental advance in the process of riveting for a long time. As a matter of fact, we now have at least as much information about the properties of welds as of rivets. Many of the variables in welded joints are recognized and can be either controlled or quantitatively evaluated. But, as the following list of problems is intended to suggest, there is ample opportunity, not to say a pressing need, for developing fundamental theories concerning the properties of welded joints, as well as for collecting accurate quantitative information.

It is hardly necessary to point out that physical tests of welds of unknown quality are of indeterminate value. Except for tests in which defects are intentionally studied, welds for physical testing should be at least radiographed and the qualification of the welders doing the work should be ascertained in advance.

1. Fatigue Tests.—In view of the impossibility in the absence of experimental data of deciding on permissible design stresses for welds under the common conditions of alternating or pulsating stress, it is surprising that remarkably little is known about the fatigue value of welds made under conditions in this country. A complete bibliography on all phases of the fatigue testing of welds is available at the offices of the AMERICAN WELDING SOCIETY. It appears that practically nothing is known about the fatigue limits of non-ferrous and alloy steel welds and that only the rotating-bend fatigue value of mild steel welds (arc and gas, butt joints) is known with any accuracy. The results of the extensive German and British fatigue tests on welds are not directly applicable in this country on account of major differences in welding procedure. The following problems are most important at present.

(*a*) Rotating-bend fatigue tests on butt welds in alloy steels, cast iron, and non-ferrous metals, arc, gas, resistance, atomic hydrogen, at low and high temperatures (−40 to 350° C) as well as at room temperature. The most important alloy steels are the low-alloy structural steels and the corrosion resisting steels (5–30% Cr and 18–8) If possible, corrosion fatigue tests on welded joints in various media should be performed.

(*b*) Fatigue tests on full-scale, as-welded structural connections and sections, duplicating service load cycles as far as possible. The relative fatigue value of end and side fillet welds as compared to butt welds is still not known quantitatively even for plain-carbon structural steel. The fatigue value of various types of welded built-up girders and connections to them, such as welded seat angles, and of spot and seam welded assemblages is particularly important; such tests have been carried out in several laboratories in foreign countries.

(*c*) Fatigue tests on butt welds (arc, gas, resistance, etc.) under different types of stress, e.g., reversed bend, pulsating bend, reversed torsion, alternating combined tension and bending, etc.

2. Static Tension and Column Tests.—(*a*) Tensile (shear) strength of spot, seam and flash welds in sheet (alloy and non-ferrous), particularly with reference to the arrangement of spots, zig-zag seams and machine variables, such as pressure dwell. Column, bend and compression tests on spot, or seam-welded box girders and spars are needed not only to check design practice but to improve the efficiency of the welds.

(*b*) Quantitative study of the relative lowering of static tensile and shear resistance of stress-annealed butt, fillet and pipe welds (all processes and materials) caused by the different types of defects, such as gas holes, coarse grain, poor penetration, each type studied independently of the others. These relative decreases may then be compared with results of X-ray inspection, nick-break tests and specific gravity determinations on the same joints.

(*c*) A detailed study of the static load behavior of two materials in intimate contact and having different elastic properties. If, for example, mild steel is welded with an alloy steel electrode of high strength and low ductility, is the joint stronger or weaker than base metal and to what extent is its ductility affected?

(*d*) Column tests on welded built-up sections to determine their rigidity or resistance to buckling compared with riveted or rolled sections.

(*e*) Tests on notched tensile specimens of all-weld-metal or welded joints. With butt joints the tests would aid in the possible standardization of round-notch specimens. With both all-weld-metal and joints the tests would provide fundamental information on notch-sensitivity.

(*f*) A study of all standard weld tensile test specimens to determine their relative sensitiveness and accuracy.

3. Impact Tests.—The impact test is specified in standard specifications for welded products in this country and abroad. A review of the literature on impact tests of welded joints appeared in the April 1936 issue of the AMERICAN WELDING SOCIETY JOURNAL. This review together with current developments in welding suggests that the following problems are important:

(*a*) Notch Location. Tests are still required to show the most advantageous location or locations of notches in V, U and X butt welds for notch impact specimens. A German specification this year requires quite a complicated set of impact specimens for welds. An impact test using large specimens, possibly unnotched, and requiring a machine that could be cheaply built in the ordinary shop might become useful.

(*b*) Tensile and Shear Impact Tests. These tests, particularly the former, are strongly advocated for weld testing by a number of experts. Detailed information on the impact characteristics of welds (mild and alloy steels, non-ferrous, low and high temperatures, type of specimen) is needed for these important types of loading impact tension and impact shear.

4. Creep Tests.—The bibliography on creep, available at the offices of the AMERICAN WELDING SOCIETY, shows there is an unaccountable lack of experimental creep data on welds, which are now used to a very large extent in boilers, stills and other apparatus operating at high temperatures.

(*a*) Creep Tests on all-weld-metal, butt and fillet welds and welded pipe joints (arc, gas and atomic hydrogen, alloy steels such as 4–6% Cr, non-ferrous metals such as copper and aluminum which creep at relatively low temperatures).

(*b*) Creep experiments to determine the nature of plastic flow in heterogeneous materials, such as welds and to determine the effect of stress raisers or notches, often present in welds, on creep and short-time high temperature tensile strength. Basic rules for designing welded joints, such as *V* or *X*, could probably be deduced from experiments of this sort.

5. The Nature of Fracture in All Types of Weld Metal.—The investigation should examine all types of welds (especially alloy steels, such as 18–8 and non-ferrous metals) by subjecting them to fracture by normal and shear stresses, static, impact and fatigue. Microscopic and perhaps X-ray diffraction examination of the fracture and its vicinity would go a long way toward answering the question, "is weld metal cast metal, or something else?"

It has often been stated that the fracture of the static tensile specimen, apart from elongation or reduction of area, gives a fairly definite indication whether a steel will be brittle or not in the impact test. Does this statement apply to welds and weld metal in general?

A further aspect of this investigation should be the correlation of information on thermal checks, cracks and flakes in castings and forgings to shrinkage cracks in welds.

6. The strength and ductility of butt welds as affected by carbon, silicon and manganese content of base metal and filler rod. (See Appendix I, II and III.)

Investigations of the effect of carbon, silicon and manganese on the strength and ductility of welds have left much to be desired. A study including tensile, bend, and impact tests of welds (gas, arc and atomic hydrogen) in a series of plain carbon steels with the same Si and Mn contents but with carbon ranging from 0.1–0.7% is required to determine the carbon limit for welds that must develop a specified strength or ductility. The filler rod may either match the composition of the parent metal or be low-carbon steel. Similar studies using plate with constant carbon but with Si or Mn varying from nil to 3% are also required, as well as studies with, for example, 2¼% Ni steel, to determine the effect of increasing carbon content.

7. Welding at Low Atmospheric Temperature.—The effect of cold weather welding on the mechanical properties of the welds produced in mild and structural steels is not clearly known. Arvidsson,* who describes the erection of an all-welded highway bridge in Sweden which was started in August and completed in December, states that below 15° C. welding cannot be carried out without special precautions, such as preheating with gas flame or blow lamp. Preheating of mild steel stock prior to deseaming with the oxyacetylene flame, according to E. E. Thum** is necessary in very cold weather (−30° F.) to prevent cracking. The difficulties at low temperatures are apparently not solely due to shrinkage stresses, for Bibber† found that the temperature of the metal upon which the weld is deposited has a great influence on the physical properties of the weld metal. As the preheating temperature is raised, the strength decreases but ductility increases. It has, however, been shown by Freiday‡ that reliable welds can be made in frosty weather. Extreme cold weather and high winds prevailed during the arc welding of a 12¾ inch o. d. steam pipe (8400 ft. long, ⅜ inch lap-welded steel pipe) containing 496 main welds. An accidental test which subjected some of the welds to impact stresses, fractured a pipe support but none of the pipe welds failed. After a year in service the line was entirely satisfactory. Faltus§ also found no difficulty in field welding mild steel structural work during hard frosts provided the sequence of welding was suitable (type of electrode not stated). It is common knowledge, of course, that high-carbon material, such as rail steels, should not be welded in cold weather without preheating.

The contradictory evidence shows that the effect of welding at low temperatures on the physical properties of welds is a problem of immediate importance. A complete series of tests on gas and arc welds prepared in zero weather should be made, including tension, bend and impact, to determine the extent, if any, of the decrease in physical properties. Supplementary to the physical tests, shrinkage stresses and their distribution as a function of temperature of parent metal should be measured.

8. Bend Tests.—A critical review of bend testing methods has recently been made by Professor M. F. Sayre (AMERICAN WELDING SOCIETY JOURNAL, **14**, (12) 2–10, 1935).

(*a*) If the weld metal has a much higher yield point than parent metal, it is almost impossible at present to evaluate the bend elongation. Experiments to correlate the ductility of all-weld-metal specimens with the bending elongation of such weld metal in joints in plates having high and low yield points would perhaps provide the required information.

(*b*) Tests to evaluate the characteristics of side-bend and root-bend specimens.

Group B—Metallurgical

1. Fundamental Studies of Slag-Metal Systems.—The reviews of recent literature on alloy steels and non-ferrous metals (Appendix IV and V) show that data are accumulating on the distribution of elements between metal and slag in welding. The interpretation of the information is not yet clear because the phase relationships of the slag-metal systems involved have not been studied with the temperature and conditions of arc, gas or atomic hydrogen processes in mind. It should be remembered that relatively small percentages of oxygen, silicon and other elements in weld metal or electrode exert profound effects on physical properties, spattering and weldability. The metallurgy of the welding of gray, malleablized and alloy cast irons is a neglected subject as shown by recent literature (Appendix VI).

2. Effect of Heat of Welding on the Base Metal with Particular Reference to Alloy Steels, Cast Iron and Non-Ferrous Metals.—Welding conditions for alloys are determined in part by the properties of the heat affected zone, which can be regulated by the rate of energy supply to the weld. In studying the effects of welding heat on the metal adjacent to the weld, two objectives should be kept in mind: First, under a variety of conditions what effects are produced as measured by hardness, corrosion-resistance, or other properties? Second,

* Arvidsson, E. D., *Weld. Ind.*, **3**, 163–166, 1935.
** Thum, E. E., *Metal Progress*, **29**, (5), 38, 1936.
† Bibber, L. C., British Iron & Steel Inst. Welding Symposium, II, 29–37, 1935.
‡ Freiday, J. A., *Mech. World & Engg. Rec.*, **99**, (2569), 321, March 27, 1936.
§ Faltus, F., I. & S. I. Symposium, I, 101, 1935.

how may adverse effects be avoided either by changing the welding procedure or by subsequent treatment?

For structural steels the problem may be subdivided as follows:

(*a*) Determination of a heat treatment, which may be called the "weld quench," that simulates the effect of the welding heat on the adjacent base metal just next to the band. This is generally the region of maximum hardness. As plate thickness and rate of heat input will affect the weld quench, their relation should be investigated and some standard rod-size, amperage, arc length, welding speed and plate thickness recommended.

(*b*) Study of series of alloy steels varying by only one element, such as nickel, chromium, molybdenum and vanadium. Determinations of hardness and bend ductility should be made. It should be remembered that alloy steels are not welded indiscriminately by the same procedure; in experimental work it is essential that changes in procedure be studied before conclusions are drawn.

(*c*) Effect of preheat temperature on hardness produced during the weld quench, and arrangement of alloys into groups depending on the preheat required to maintain a standard of bend ductility adjacent to the weld.

3. Flame Hardening with the oxyacetylene torch, using alloy steels (air and water hardening) and possibly non-ferrous alloys, such as duralumin and beryllium-copper. The metallurgical effects are different in spot and straight line hardening and especially in closed circle hardening where the end effect is important.

4. The technique of hardening welds by carburizing and nitriding.

5. Surface Condition of Steel.—The surface condition of steel produced by pickling or cold-rolled has sometimes been found to have an effect on penetration in arc and resistance welds and in brazing. The causes should be studied in a variety of steels.

6. Surface Tension effects of different types of weld and brazing metal on steel, copper and alloys in general. Surface tension, which has a large influence on penetration and weldability, should be studied with strict control of atmosphere and metal composition.

7. Materials for making spot- and seam-welding electrodes. (See Appendix VII.) Alloys combining favorable thermal and electrical conductivities and high temperature strength or hardness should be studied by a non-partisan research group; it may be found that different materials are required for electrodes of different shape.

8. The metallurgy of welding difficult metals and alloys under water or other liquids, such as carbon tetrachloride.

9. The metallography of austenitic welds in pearlitic cast iron. A microscopic and hardness survey of welds (cold and preheated) made with several types of austenitic filler rods in a single common grade of pearlitic cast iron would reveal the sources of defects as well as the probable field of application of each rod. A related problem is the metallographic study of welds made with high-chromium rods to determine the extent and effects of nitrogen pick-up, either from the atmosphere or from high-nitrogen base metal.

10. Assembling complicated magnets of nickel-aluminum and other magnet steels by fusion welding followed by suitable heat treatment.

11. Effect of the hydrogen content of weld metal on the tendency to shrinkage cracking.

Group C—Physics

The current problems in the physics of welding are largely indicated in the appended summaries of recent literature on metal transfer and X-rays. (Appendix VIII and IX.) The following problems are outstanding.

1. Mechanism and rate of metal transfer in arc welding, including overhead welding and controlled atmospheres.

2. Laws governing magnetic disturbances in A.C. and D.C. Arc Welding and how these disturbing effects may be eliminated.

3. The effect of alloying elements, such as manganese, and of multi-constituent coatings on arcing characteristics of the electrode. The effect of a large number of single coating constituents being known now, it would seem most desirable to determine their combined effects as in commercial coatings. Perhaps a spectrographic study providing information on the excitation of coating components singly and in combination might usefully supplement the oscillographic mode of attack on stabilization problems.

4. D.C. and A.C. Arc temperatures with various metals and alloys, in various atmospheres, and over a wide range of amperage.

5. Calorimetric Study of Carbon and Metal Arc and Gas Welding.—This study would be of great practical value if the heating effect of various conditions on the material being welded could be determined quantitatively. Such results might lead to methods of predetermining amounts of shrinkage by mathematical analysis.

6. Theory of Combustion in the oxyacetylene, oxy-hydrogen, and other welding flames, and metal transfer during welding with these flames.—A spectroscopic examination of different regions of the flames using various gas ratios, with and without introduction of the welding rod would probably suggest means for more efficient gas welding procedures.

7. A quantitative study of the path of the current in resistance welding, particularly spot and seam welding. It has been suggested that the current path for small current and thick plates could be determined. The path for thin sheet and high current might then be mapped approximately by extrapolation. The current distribution in resistance butt welding bars whose ends are slightly conical should also be determined.

8. Non-Destructive Tests of Welds.—(*a*) Correlation between X-ray photographs and specific gravity, nick-break test and physical properties. This investigation should include a quantitative check on several qualitative X-ray tests that are used in some quarters.

(*b*) Investigation of the supersonic vibration method and its sensitivity to common defects in welds.

(*c*) Investigation of electrical and magnetic methods of weld testing with particular reference to fillet welds.

9. The Nature of the Bonding Force in Welding.—If the base metal is not melted, as in brazing, the bonding forces are created by intercrystalline penetration of filler metal into base metal, and by diffusion into or absorption on base metal. During welding, the base metal is melted and the molten filler rod simply increases the volume of metal that subsequently solidifies. The problem is to study the nature and strength of the bond between base metal maintained at different temperatures and molten metal poured on its surface. Information obtained from these tests, admittedly difficult to control, might then be compared with the strength of joints in solid-solid and solid-gas "welding." The solid-solid weld is controlled by a balance between sintering temperature and pressure, and probably its strength is primarily an expression of mutual

absorption forces unless as in electrodeposition, the coating adherence may be controlled by valency effects. The nature and strength of the adherence between base metal and sublimed deposits is affected to a great extent even by monomolecular absorbed films of oxides, for example, which are particularly disastrous in solid-solid or pressure welding. Solid-gas welding has been observed in some reversed polarity arc welding; solid-solid welding undoubtedly plays a part in flash and other types of resistance welding.

Group D—Welding Procedure

Apart from proprietary methods there is much to be done on the most satisfactory procedures for welding metals and alloys by all processes. The conflicting statements that occur in recent literature on welding alloy steels and non-ferrous metals, Appendix IV and V, are proof that well-planned experimental work is urgently needed, including a study of welding variables as well as of physical properties and microstructure of the welds. It is time that opinion and fragmentary information should be replaced by demonstrated facts.

1. Speed of welding and the relation between voltage and amperage. A record of the power consumption at the arc with these tests would provide definite information along a direction in which very uncertain information now exists. There is an analogous problem in gas welding, namely, the relation between welding speed and gas consumption.

2. Proper welding procedure to obtain satisfactory welds in hydrogen and other gases. The experimental work on this problem need not involve the actual making and testing of welds since the chief problem is the amount of metal discharged from the tip of the electrode. Automatically controlled experimental conditions should preferably be adopted.

A careful study should be made of the amount of electrode melted down with different arc voltages from the lowest to the highest practicable and also with the lowest and highest current densities practicable for any size of electrode. Different combinations of experimental conditions should be tested and a record made of the rate at which the metal is melted and also the rate at which it is deposited. Bare and covered electrodes, ferrous and non-ferrous, should be investigated, along with D.C. as well as A.C. and atomic hydrogen.

The objects of these experiments would be to determine the nature of metal transfer, to determine if there is an optimum current density applicable for all sizes of electrodes, to discover the effect of electrode composition on deposition efficiency, as well as a number of other features which the experimenter would realize as the work progressed.

3. Effect of peening on the quality of welds. Although it is known that peening reduces shrinkage stresses in welds in mild steel up to 50%, it is still a question whether peening has a favorable effect on impact or fatigue value. The temperature range in which peening is done and the point at which the blow is struck are the two major factors. Some believe that peening the weld metal is undesirable but that peening the base metal adjacent to the weld is helpful. It is suggested that experimental peening be performed with an air hammer supplied with a constant air pressure.

4. Capacity to produce resistance welds of constant quality in different individual and total thicknesses of material using a given setting of the machine. Tests to determine optimum current, pressure and dwell for all resistance welding processes, as determined by physical properties and economy.

5. Effect on resistance welding of coatings such as dirt, oxide, and zinc, nickel, tin, or other platings on steels, brass and other alloys.

6. A comparison of forehand and backhand gas welding for non-ferrous alloys. The comparison should include the time of welding for various plate thicknesses ($^1/_{16}$–$^1/_2$ inch), gas consumption, fatigue of operator and quality of welds.

7. The effect of annealing above or below the critical point on the physical properties and machinability of welds. The tests should be directed particularly toward improving gas, arc and resistance welds in high-carbon and alloy steels, and cast iron. The problem is particularly acute in welding two steels having widely different critical ranges.

8. Spot welding precious metals and alloys.

Group E—Structural Studies

The greatest advantages to be obtained by the use of welding in fabricating structures of all kinds can only be obtained by adopting structural methods suited to welding. At present the influence of joining processes, such as nailing, pinning and riveting, which are basically different from welding, is felt to too great an extent in welding design. But the best design methods for welded structures can only be developed on the basis of experimental studies of the stress distribution and shrinkage of welded joints. The summary of recent literature on these topics (Appendix X and XI) shows that considerable progress is being made; yet a number of fundamental problems are still unsolved.

1. Stress distribution in full-scale welded structures. Experimental and mathematical analysis of stress distribution in beam and column connections and in built-up girders should be made in order to deduce reliable design formulas and to determine safe design practice. Experimental studies should take weld shrinkage into account.

2. Photoelastic studies of the stress distribution in welded joints. Although the technique of the photoelastic study of welded joints appears to have been worked out, there are relatively few quantitative data on the magnitude of stress concentrations in typical welded connections; for example, transverse and diagonal butt joints with intermittent welds, several common marine types of lap joints, turned-up sheet welds, welded stiffening webs and plates in beams, crossing butt welds in all pressure vessels; pinned or riveted strap joints strengthened by welding, right angle butt welds. In addition to the information obtained from photoelastic models containing no defects, it would be very useful to know the maximum increase in stress concentration created by typical defects such as blowholes, undercut and faulty penetration. Thus, the maximum stress concentration should be determined in corner welds of various types with poor root penetration.

3. The limitations of model studies. The limitations inherent in the study of stress concentrations in models of welds should be determined and unequivocally stated. Extensometer studies of steel models sometimes are complicated by bi-axial stress conditions which, for the sake of simplicity, are disregarded by the experimenter. Often the distinction between strain concentration and stress concentration is not precisely pointed out, especially in models stretched in the plastic region, and in rubber models. Again, model studies do not generally envisage the possibility of redistribution of stress upon the occurrence of slight plastic deformation in the regions of high stress concentration, although it is commonly believed that such redistribution occurs in service. A

clear statement of the proper application to structural design of data obtained from model studies of welds would forestall the possible misuse of stress concentration factors.

4. The degree of restraint that may be counted on in welded beam connections. The quantitative study of rigidity in welded construction has been advanced by vibration studies of bridges and machine tools but a great deal of information is still required. A particular problem is the relative value of welding rotor hubs to shafts compared to press or shrink fits.

5. Experimental check on proposed theoretical methods of computing permissible stresses in welded joints, with special reference to fatigue.

6. The relative stress transfer in nozzle openings in pressure vessels of riveted and welded construction. A comparison should be made between the stress concentrations occurring in welded and riveted types of construction, with special reference to piping, tubing and flanged joints. The experiments should suggest efficient methods of reinforcement.

7. Quantitative studies of the internal stresses caused by welding. (See Appendix IX.)

(*a*) Theoretical solution of the thermal stress problem for welds in different metals, taking into account the plastic range, speed of welding, dimensions of joint and plates and the existence of bi-axial and tri-axial shrinkage stress conditions.

(*b*) Shrinkage stresses due to multiple-layer welding.

(*c*) Shrinkage stress measurements in welds in pure iron and high-alloy steels to determine the effect of temperature of critical point or range (A_3 or A_1) on shrinkage stresses.

(*d*) The effect of microstructure of base metal on warpage in welded sheet.

(*e*) Stress relief. Except for welds in low carbon steel there is little quantitative information on the extent of stress relief at different stress annealing temperatures.

(*f*) The investigation of shrinkage stress distribution in photo-elastic material subjected to local heating.

(*g*) Shrinkage stresses in spot and seam welds.

Group F—Chemistry

1. The chemistry of fluxes and coatings.—(*a*) Viscosity, melting and boiling points, and surface tension of typical flux and coating compositions.

(*b*) Is the action of the coating on coated or shielded arc electrodes in excluding nitrogen mechanical or chemical? Experiments should be made in which a weld is made in air or nitrogen with a coated electrode, and then with a bare electrode using a flux of the same composition as the coating. The weld metal and slag in both experiments should be analyzed, particularly for nitrogen. If the action of the coating is mechanical, that is, if the volatilization of carbonaceous or other material forms a mechanical shield around the arc despite the turbulent conditions, then the second weld may be expected to contain nitrogen. If the action is chemical both welds will be free from nitrogen and the gases around the arc (which might be analyzed perhaps partly by spectroscope) or the slag itself will contain stable nitrogen compounds.

2. Corrosion of welds.—The summary of recent literature on the corrosion of welds (Appendix XII) shows that the following problems require study:

(*a*) The rate of corrosion of all kinds of welds in various atmospheres and media at different temperatures.

(*b*) The theory of the corrosion of welds. Some of the factors that are said to affect the corrosion properties of welds are: (1) Rough surface of weld; (2) difference in electrode potential of weld metal due to difference in chemical composition, in microstructure and in other properties; (3) slag content in and around weld metal; (4) highly stressed condition of unannealed weld metal and adjacent base metal. The relative importance of these factors should be estimated for welds in ferrous and non-ferrous materials.

(*c*) Procedures for testing the corrosion properties of welds. Accelerated methods are not necessarily implied. A procedure for obtaining the maximum measurable corrosive effect under service exposure is required using specimens of convenient size prepared under normal welding conditions.

(*d*) The effect of corrosion on the mechanical properties of welded joints in heat-treatable alloys. Welding sometimes sensitizes the heat affected zone of alloys to intergranular or accelerated corrosion. The problem has been studied to exhaustion in 18–8 and closely related alloys but has been neglected in light metals and copper alloys.

(*e*) Reagents for rapidly detecting traces of flux on improperly rinsed welds in light alloys.

Group G—Personnel

1. Time and motion study of hand welding by arc and gas processes.

2. Physiological effects of arc radiation, and fumes from electrodes, flux, zinc, paint or base metal, on the welding operator.

3. Aptitude tests for welders.

APPENDIX I

Recent Literature on the Effect of Carbon on the Properties of Fusion Welds in Steel

The average residual carbon content of different kinds of welds, according to Paterson[1] is: Low-carbon bare wire, 0.2 to 0.4%; slag-coated (organic flux) 0.03 to 0.055%; slag-coated containing organic matter, 0.05 to 0.075%. The problem of carbon content in plain-carbon steels is concerned with fatigue value and ductility of welds rather than with process characteristics. Thus, when Boden[24] states that the German Railways do not use plain carbon steel with 0.35% C in car frame and bridge construction on account of its poor weldability, the latter term probably embraces physical properties at least as much as characteristics of the welding process. For arc and spot welding, low-alloy steels (0.20 to 0.25% C) are used instead of medium carbon for frames. In the course of a review of present-day welding practice, Zimm[30] states that the carbon content today is usually held at or below 0.2%. Higher carbon steels are subject to blow-holes, poor penetration and undesirable hardening effects. According to Séférian,[25] plain carbon steels are weldable by all processes but weldability (defined as uniformity of structure and physical properties) decreases with increase in carbon according to the formula: $S = \frac{1}{C\% - 0.10}$ applicable above 0.25% C; up to 0.15% C the weldability is perfect.

Extensive tests by K. L. Zeyen[2] show that loss in carbon on welding with rods containing 0.65 C is 45% in gas welds and 70 to 75% in arc welding, bare or coated electrodes, A.C. or D.C.; the loss was 20% less in 3-layer deposits than in single layers. Impact and bend values were much lower in steels (0.1 to 0.7% C, arc welded with high-grade covered electrodes containing 0.1% C) with 0.3% C or more than in steels with less than 0.2% C. Welds in higher-carbon steels had no greater fatigue strength in bending (about 22,000 psi) than in the lower-carbon steels. In his most recent article Zeyen states that covered electrodes of low-alloy, low-carbon structural steel can be successfully used for steels $^1/_2$ inch thick containing up to 0.56% C and up to $^1/_4$ inch thick with 0.60% C. Using a special alloy covered electrode (analysis not given), Brennecke[27] obtained the same physical properties in butt and fillet welds in medium-carbon steels (0.40–0.60% C, 0.6 Mn, 0.25 Si, $^1/_2$ inch thick, 0.16 inch electrode) as in unwelded plate. Blow-holes due to CO were absent as well as cracks. Streb and Kemper[3] showed that the bend elongation in unannealed gas welds was zero at 0.4% C, but that annealing above A_3 restores ductility. Arc welds with more rapid cooling would magnify the effect of carbon.

Csilléry and Péter[4] give micrographs, weld analyses, tensile and impact values for rail steels (0.6% C) welded with electrodes containing 0.1 to 1.0% C. The hardness in the heat-affected zone of oxyacetylene welded rail bonds (copper, using copper filler rod containing P and/or Ag but free from Sn) was lower than in the rail head itself for medium-manganese rails, but considerably higher (308 Brinell compared with 250 in head) in 1% Cr rail, according to Bainbridge.[31]

Holler and Frankenbusch[5] give complete information on tensile, bend and impact properties, and microstructure of butt gas welds in seven steels (0.05 to 0.37% C) with rods of the same analysis as the steels; the effect of hot forging and reverse welding are also given. The high-carbon steels had reasonably good ductility. Becker[6] studied the tensile, rotating-bend fatigue and impact properties of gas, atomic hydrogen and arc welds in mild steel with four rods containing 0.08 to 0.32% C. The higher the carbon, the greater the porosity and the lower the physical properties; the expected decrease in oxides with increase of carbon content of welding rod (most of the carbon was lost in each type of welding) was thus counteracted. Stursburg[7] had difficulty in obtaining good gas welds in plain carbon steels containing about 0.35% C unless strict temperature control was observed. Annealing and forging were of no effect, which is in disagreement with most investigators.

Roberts[8] studied microstructure and hardness as a function of distance from weld (heavy coated electrodes) in steels with 0.05, 0.18 and 0.52 C and showed that stress-relieving at 1100–1200° F. lowered the hardness peak in the weld somewhat and that multi-layer welding breaks up the Widmannstätten structure. Low-alloy structural steels (80,000–100,000 psi tensile) containing more than 0.14% C, according to Kinzel,[26] when welded show a moderate increase of hardness which, although not of much importance in butt welds, yet makes stress-relief advisable.

Rapatz[9] places the limit of ductile welds at 0.4% C and shows that brittleness in higher-carbon steels is due to the formation of a hard brittle zone. Other contributors to the Symposium in 1935 (Déglon, Hodge, A. M. Roberts, Pearson, Hatfield) discuss aspects of the carbon question, and the Director of the British Admiralty advises that carbon content be restricted to a maximum of 0.3% for structural welding, which is in agreement with others who expressed opinions on the subject. The recent bridge specifications of the American Welding Society restrict the carbon content to 0.25%, and Swiss and German specifications are even more cautious in this field. A. S. T. M. specifications permit up to 0.35% C, however. Chapman[21] states that the carbon limit in deposited metal for pressure vessels is not usually above 0.15%. There is a belief, expressed by Lohmann and Schneider,[10] whose review contains a number of references to carbon content, that plate thickness determines the procedure to be adopted for arc-welding high-carbon steels.

From tests of the mechanical properties of plain-carbon and low-alloy steels, shown in the following table and welded with coated electrodes of presumably the same composition as base metal, Meunier and Rosenthal[32] deduced that steels with 0.25–0.40% C were semi-weldable and steels with more than 0.40% C were un-

Results of Meunier and Rosenthal[32]

	Carbon	0.02	0.10	0.256	0.33	0.44	0.142	0.195	0.219	0.20	0.235	0.14
	Manganese	(Armco)	0.605	0.906	0.861	1.16	1.32	1.33	1.03	0.37	0.47	0.75
	Silicon		0.1	0.066	0.19	0.1	0.33	0.58	0.34	0.38	0.27	0.1
Analysis	Sulphur	≤0.2			0.02							
	Phosphorus		≤0.06	≤0.06	0.023	≤0.06						
	Chromium								0.27	0.59	0.47	0.45
	Copper						0.36	0.31	0.55	0.5	0.55	
	Molybdenum							0.10		0.1	0.14	0.45
Mechanical Properties of Base Metal	Tensile Strength		57,000	74,500	87,500	104,000		74,000		78,000	80,500	79,500
	Yield Strength, psi		39,600	46,400	55,000	64,000		51,000		57,000	57,000	60,000
	Elong. 7d %		25	22.8	23.5	18		20		23.6	23.6	23
Bend Angle Degrees	Unwelded		180	180	180	180	180	180	180	180	180	180
	1 Layer		180	180	110	8.5	135	90	90	115	90	100
	4 Layers		180	180	150	73	180	180	180	180	180	180
Bend Elongation %	Unwelded		45	45	45		45	45	45	45	42	45
	1 Layer		34	28	25	5	23	19	19	20	17	13
	4 Layers		39	40	35	27	32	30	33	47	46	28
Notch-Impact Value Mesnager Kgm./cm²	Unwelded		>25	11	10.2	11.2	10	10	10	14	13	
	1 Layer		16	9.5	5.2	0	10	8.3	8.7	11.5	10	
	4 Layers		16.2	12.3	10.1	10.7	10	10.7	10.5	17.5	18	
Maximum Brinell Hardness	Unwelded	107	130	150	182	200	165	176	180	145	155	160
	1 Layer	130	152	197	270	530	235	260	260	235	250	240
	4 Layers	113	144	167	192	240	190	200	195	190	185	200

weldable. They also found that as the current for welding plain-carbon steel with 0.44% C was raised from 100 to 400 amps., the coefficient of heterogeneity, defined as the ratio in per cent of maximum hardness in transition zone to hardness of base metal decreased from 270 to 150%, but as the speed of welding was increased from $1^1/_2$ to 7 inches per minute, the coefficient rose from 130 to 260. A study of the microstructure showed that blow-holes can be prevented in medium carbon steels by using a properly coated electrode (no composition given) but that cracks can be entirely suppressed in the steels with over 0.4 C only by preheating to 300° C.

Jasper[11] showed that the elongation (in 2 inches) was 35 to 45% in welds in 0.2% C steel and 20 to 30% in 0.35–0.45 C steel welds. Dustin[12] attributes the brittleness of welds in high-carbon steels (over 0.3% C) to microcracks formed during cooling. These cracks in arc-welded high-carbon steels (0.52 C, 0.60 Mn) according to Armstrong,[22] are caused by shrinkage stresses which apparently attain very high values in the hardened zone in the base metal adjacent to deposited metal. This zone, it may be assumed, is incapable of undergoing plastic flow under the high stresses. Preheating the scarfs up to 1250° F. before welding prevents cracking but does not improve impact and bend properties. Unexplained impact behavior and several fundamental questions raised in the discussion of the paper remain for future investigation. Hartley and Vivian[33] describe the arc welding of pipe lines made of steel containing 0.3% C. A study of the Widmanstätten structure in weld metal and junction zone of gas and arc welds in plain-carbon and low-alloy steels containing up to 1% C has been made by Belaiew and Seferian[34] who also studied the effect of annealing on impact value.

Reiter[13] states that electrodes for surfacing worn locomotive tires should not contain over 0.2% C if cracking is to be avoided. An extensive series of tests on resistance welds (similar to the tests reported in 1933 by Vér on flash welds) in five plain-carbon steels containing 0.21 to 1.28% C has been reported by Hasa and Beneš.[14] Ductility and impact values of the as-welded specimens were only 10 to 20% of plate metal in 0.21 and 0.43% C steels. Heat treatment increased this value to as high as 80%. In steels with over 1% C ductility (red of area) and impact values were nil; spheroidization considerably improved these properties. The hardness in the weld in 0.43% C steel was 105 B Rockwell (275 Brinell) in 0.73% C 37 C Rockwell (345 Brinell). Tensile, bend and fatigue properties of arc and flash welds in cast steel containing 0.31–0.39% C were shown by Sampson[28] to be satisfactory regardless of surface preparation. However, MacFarland[29] states that a considerable increase in carbon content of steel to be flash welded may require a lengthening of the time of flash to avoid brittleness. In the spot welding of plain carbon steels containing 0.08, 0.42 and 0.83% C, according to Dussourd,[20] the rate of cooling must be comparatively slow in the two higher carbon steels to obtain good shear strength. Contrary to Hasa and Beneš, Dussourd states that fusion occurs in the usual spot resistance weld. A Russian investigator reports[15] that tensile tests at −185° C. showed an increase in strength of 100% in plate containing 0.32 C, 0.63 Mn over that at +20° C., but only 56% in the welded plate and 27% for all-weld-metal of the same composition.

Ronay[16] states that the higher the carbon content of the electrode, whether bare or coated, the higher the rate of melting. Boiko[17] studied the effect of carbon content of coating on the nitrogen and oxygen contents of arc welds. The analysis of cast steel for welding should be 0.17–0.25 C, 0.5–0.8 Mn, 0.25–0.40 Si, 0.06 Max P, or S, according to Longbottom.[18] Portevin and Leroy[19] give the percentage change in composition during gas welding of steels containing up to 1.2% C. The effect of carbon content in welding 18–8 is dealt with by Pratt[23] see Appendix IV (*b*). Séférian[25] states that the carbon content of copper steels (0.4–0.5 Cu) should not exceed 0.15–0.20% C for best weldability.

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APPENDIX II

Recent Literature on the Effect of Silicon on the Fusion Welding of Steel

Chapman[1] states that silicon is easily oxidized and hard to control in alloying percentages, and that the introduction of this element in welding steels is in the experimental stage. Epstein, Nead and Halley[2] believe that the gas evolution arising from the reaction of carbon with FeO may be largely overcome by adding manganese and silicon. The percentage change in chemical composition during gas welding is given for steel containing 0 to 1.2% C, 0 to 2.0 Si, 0 to 2.0 Mn by Portevin and Leroy.[3]

At the recent Iron and Steel Institute Symposium, Shepherd and Moritz[4] point out that highly basic fluxes deprive deposited metal of Mn and Si, but acid fluxes, usually containing a high percentage of SiO_2 tend to preserve Mn and even increase Si due to reduction of SiO_2 in the metallic arc. Swinden[5] is in general agreement, but implies that the presence of Si in deposited metal has a bad effect on physical properties, whereas Reeve[6] shows a remarkably high Si content in his most successful weld metal, welds with 0.25 Si and 0.54 Mn (shielded arc) being better in Izod and percentage elongation (and low in N_2, 0.01%) than welds with 0.014 Si and 0.09 Mn (with 0.04 to 0.18 N_2). The best weld metal appears to be produced under the most highly reducing conditions. These conditions would

require a minimum of "oxidizing" and a maximum of "reducing" elements in a siliceous slag covering, together with a high arc energy to ensure as complete a reaction as possible. Paterson,[7] whose review of the Symposium papers is largely followed in this paragraph, emphasizes the need for the analyst to distinguish between Si in solid solution and Si as oxides and slag.

Hoyt,[23] by means of fractional oxygen determinations, has shown that bare electrode deposited metal analyzes 0.01% Si, of which 98% exists as oxide; metal deposited by cellulose-covered electrodes analyzes 0.20% Si, of which 75% is metallic. In the latter deposit the inclusions are practically pure silica, no FeO being present. Hatfield states that opinions differ regarding the effect of Si, welding rod manufacturers tending to limit the Si content. Blomberg[24] observes that Si, Mn and Al are the main elements controlling blow-holes in steel ingots and that aluminum is not used in practice for electrode coatings. Silicon, as ferro-silicon, silico-spiegel or carborundum, is less effective than Al. It may also be introduced into weld metal by reaction between silicate slag and organic coating. The electrode is seldom used to introduce Si because it has a bad effect on arc characteristics, which high Mn offsets. High-silicon rods are often used for oxyacetylene and particularly atomic hydrogen welding.

Baumgärtel and Heinecke[9] found that flash welded steel containing 0.4 C, 10 Cr, 2 Si is brittle on account of its high Si content. Haardt[10] studied diffusion in steel containing 3.5 Si, 0.1 C, welded with bare and coated electrodes both containing 0.07 C, 0.01 Si, 0.4 Mn ($^3/_{16}$ inch diam.). Less Si is lost at high amperages, 175, than at low, 110, and with bare than with coated electrodes. More Si was lost in two-run than in single-layer welds, especially with coated electrodes. Diffusion of Si appeared to occur only in the molten condition. Nitrogen pick-up was less with Si than with Cr, Mn, Ni or Cu. Oxyacetylene Tips[11] gives the procedure for gas welding Cromansil (trade-mark) steel containing 0.7 to 0.9 Si. High-test (0.5 Si) and Mn-Mo steel rods are recommended and sizes are specified. Harris[19] shows that the air hardening tendencies of this steel are not displayed up to 0.15% C for arc welding; and that an effective coating of the electrode is called for to prevent oxidation of the Si, Mn and Cr.

Lawrence[12] states that the Si content of plates for fusion welding is generally limited to 0.25%. The harmful effects of excess Si or Al in the plate metal, according to Kinzel,[13] are due to refractory oxides which can be fluxed by a well-adjusted coating. Séférian[14] found that oxygen pick-up (as MnO and SiO_2) decreases in arc welding as the Si and Mn content of the plate metal increases: 0.1% Si = 0.0086 SiO_2; 2.0 Si = 0.0019 SiO_2. The problem of the equilibrium of Mn and Si in weld metal and flux has also been studied by Losana and Jarach[20] and by Pilarczyk.[25] Holmberg[15] lists Cromansil (trade-mark) 0.5 Cr, 1.25 Mn, 0.09 Si, Cor-ten (trade-mark) with Cr, Cu, Si and P and Sil-ten (trade-mark) among low-alloy steels suitable for welded vehicular construction. Leitner[16] found that steel with 0.6 Si and over gave less porous welds than low-silicon steel.

Grahl[17] discusses early literature on the weld-ability of silicon steels and determines the following physical properties of forge and flash welds in 8 steels containing 0 to 1.35% Si, 0.15–0.18 C, 0.56 to 1.06 Mn: tensile properties, cold- and hot-bend, notch impact. All properties decreased with increasing silicon. Forge welds were not so good as flash. Annealing at 860 or 1060° C had a bad effect on physical properties. The use of a flux (35% reduced iron compounds, 45% pure fluxing agent, 20% carbon) had a very slight beneficial effect. Welding temperatures and microstructures were also studied. There was no difficulty in welding the steels up to 1.35% Si. Schottky[18] states that Si impairs the forge-weldability of heat-resisting steels, and finds that arc welds in chromium steels (9 to 18% Cr) do not develop good physical properties if the plate or electrode contains 2 to 3% Si. The procedure necessary for welding an acid-resistant silicon iron (14–18% Si, 0.2–0.7 C, 0.3% Mn) is described by Malaschenko.[21] Vasilyev[22] describes the process and product of resistance welding bars and tubes of Silchrome (0.4 C, 3 Si, 9 Cr) to S.A.E. 5140; the heat-affected zone is of greater extent in the Silchrome than in the 5140.

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APPENDIX III

Recent Literature on the Effect of Manganese on the Properties of Fusion Welds in Steel

A good fundamental review of the effect of manganese in mild steel electrodes is given by Harris.[1] There is little in this text-book or in most of the recent literature to indicate that manganese is harmful in mild steel welding rods up to about 2%. Séférian[2] states that the order of oxidizability of elements in welding is the same as in steel refining, the loss in welding averaging 70 to 80% for silicon, 35 to 50% for carbon, and 40 to 50% for manganese. Leitner[3] found that the minimum content of Mn to prevent formation of blow-holes is 1.7%, and Boiko[4] points out that the equilibrium between the Mn content of coating and weld metal is intimately connected with the nitrogen and oxygen contents of the weld. The MnO_2 content of arc weld metal, according to Séférian,[2] decreases with increase of Mn in the electrode, with 0.1% Mn, 0.12% MnO_2; with 2.0% Mn, 0.006% MnO_2. Hoffmann[5] also found that increase in Mn content of electrode decreases the oxygen content of the weld. In gas welding, Portevin and Leroy[6] showed that the loss of Mn on deposition varies with the Mn content of the electrode up to 2.0% Mn. The lower content of MnO_2 in the metal with increasing Mn, however, is not explained. An increase in Mn content did not decrease the carbon loss; an increase in Si content did not preserve the Mn, but did reduce the loss of carbon. Using an electrode containing 1.45% Mn with a coating consisting largely of manganese ore, Sveginzev[27] found that the notch impact value of welds in mild steel after annealing was no

better than using an electrode containing 0.3–0.5 Mn because most of the Mn is lost during deposition. An addition of 1 to 2% Ni, however, prevented the loss of impact value on annealing (920° C.) and was as effective as 4.6% Ni.

National standards, in general, are not specific about Mn content. The German Railways actually specify 0.6 to 1.0% Mn in their harder grade of gas welding rods for joints, and require 0.5% Mn minimum in the harder grade of electrodes. Hoff[7] (see 18) states that welding by D.C. arc and gas is improved by an increase of Mn to at least 1.6%. Jasper[8] shows good physical properties in welds in structural steel containing 1.0 to 1.5% Mn, and Sutton[9] for low-carbon steels with up to 1.75% Mn. The latter states that these steels can be welded without as much coarsening of the microstructure as plain-carbon steel and that normalizing is not necessary. The Lincoln Electric Company[25] recommends 0.45% Mn in 0.2% C steel and 0.8 Mn in 0.4 C steel, and Schimpke and Horn[26] state that Mn steels containing 0.8 to 2.0% Mn give good welds but alloy electrodes should be used. The vaporization of Mn in the electrode is said to counteract oxidation of silicon so that with 0.5% Mn, it is permissible to use up to 0.15% Si. Moses[10] found that MnO is present to the extent of only 0.01% in coated electrode welds and that these welds generally contain 0.44 to 0.50% Mn but bare electrode welds contain only 0.10 to 0.13% Mn. Tests by Kleinefenn[11] showed that Mn up to 0.72% in plain-carbon steel (0.1 C) and up to 1.4% in 2% Ni steel has no adverse effect on impact properties. U. S. Navy Spec. No. 48 S 5 E, under high-tensile steel of weldable quality, lists a steel containing 0.18 C, 1.45 Mn, 0.25 Si, 0.008–0.018 V, for which the ordinary mild steel coated rod is used, according to Beard.[29]

Holden[12] states that the analysis of mild steel for resistance welded chain should be 0.08–0.10 C, 0.08–0.10 Si, 0.6–0.9 Mn, and that the Mn should be at least 20 times the sulphur. The resistance-welded chain of Nápravník and Popov,[13] however, contained 0.08–0.11 C, 0.37–0.42 Mn, 0.001 Si. Several investigators find that Mn is not beneficial. Special precautions must be observed in welding steel castings with over 0.75% Mn, according to Pearson,[14] and Helin and Svantesson[15] state that an excessive Mn content may at times cause difficulties in arc welding. Streb and Kemper[16] qualify their statement that high Mn is desirable by adding that too high Mn causes excessive slag formation. Splashing, caused mainly by FeO, could not be completely eliminated by deoxidizing the electrode metal with Mn. Electrodes could be made spatter-free by deoxidation with Si, although too high silicon content produces a viscous slag and porous welds. Tensile strength of welds is improved at least up to 0.8% Mn and bending elongation is not decreased. Blomberg[28] states that Mn is less active than Si in avoiding blow-holes but that a content of 3% Mn in the electrode with a neutral coating (pure hornblende asbestos) gives freedom from blow-holes. The Si content of atomic hydrogen filler wire can be reduced by increasing the Mn content.

It is Krupp's experience, according to Zeyen,[17] that steels with over 0.3% C cannot be gas welded in thin sections without cracking. To get equivalent strength in low-carbon steels, Aero 50 (high Mn, low C) is recommended. Aero 70 (0.4 C, 1.1 Mn) is remarkably crack resistant, may be welded with bare or coated plain-carbon, low-alloy or austenitic electrodes or by gas, and gives 180° bend angle and high strength in 0.1-inch sheets. Brillié and Séférian[33] have determined the weldability of 1% Mn steel (< 0.2 C) using the results of the Chevenard micro-tester as the criterion. Becker[18] found that bend angle, bend elongation and notch-impact value of welds in mild steel were greatly decreased by increase of Mn up to 3.15% in rod and 2.5% in weld (D.C. arc, atomic hydrogen and gas) without any gain in fatigue or tensile strength, forged or unforged. In the arc welds, which were made with bare electrodes, 1.6% Mn in the electrode (0.82% Mn in weld) had a good effect but higher contents were a disadvantage. The general opinion at the Welding Symposium of the I. & S. I. was that Mn was beneficial in mild steel welds. Several writers on the subject of alloying elements in welds neglect to mention Mn, apparently because there is little trouble with the element. Rolfe[30] has, however, noted a curious difficulty in arc welding medium—Mn, free-machining stock (0.13–0.22 C, 0.79–1.06 Mn, 0.008–0.0023 Si, 0.051–0.065 P, 0.23–0.27 S). A gas reaction probably due to SO_2 caused deep craters in the welds.

A general review of the metallography of welding austenitic manganese steel of the Hadfield type is given by Harris,[1] whose discussion of the welding rod question is not, however, particularly comprehensive. Michaud[19] recommends a low-carbon, 23% Ni rod for gas welding, and Séférian[2], while recommending the same composition, states that 0.4–0.6 Ti is beneficial. Rapatz and Hummitzsch[20] studied the microstructure of the junction zone in austenitic welds in Hadfield manganese steel and mild steel, and concluded that the martensitic zone is broader with Mn steel (17% Mn) rods than with austenitic chromium-nickel steel rods (16.5 Ni, 4 Cr). Manganese martensite had a greater sensitivity to overheating. Hatfield[24] also recommends austenitic Cr-Ni electrodes for Hadfield manganese steel. Payne[21] and Walter[22] deal with the procedure for building up wear-resistant edges with austenitic manganese steel. The former uses a Ni-Mn steel. The Lincoln Electric Company[25] also details the procedure for welding high-Mn austenitic steels with a Mn-Ni-Mo electrode (composition not given). The electrode analysis recommended by Sanderson[31] is 0.6–0.8 C, 3–5 Ni, up to 15 Mn, which toughens the fusion zone. The Toronto (Canada) Transportation Commission[32] has standardized bare Ni-Mn electrodes (0.75 C, 12–14 Mn, 3–5 Ni) for all high-Mn steel repair welding, except wearing surfaces for which a coated nickel-free electrode (1.0–1.25 C, 14–16 Mn) is used. Both electrodes are $^3/_{16}$ inch diameter and operate at 150–180 amps. Lebrun[23] states that the increase in electrical resistance of mild steel electrodes for automatic welding by small additions of Mn is not significant for short electrodes.

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APPENDIX IV

Recent Literature on Welding Alloy Steels

A—Low-Alloy Steels

Welding Aspects

A comprehensive discussion of welding low-alloy steels in pressure vessel construction is given by Chapman,[1] whose major recommendation for avoiding cracking in alloy steels is to use plate free from slag. The addition of alloys makes the weld more sensitive to stress-relieving temperature. Molybdenum up to 1% improves welding properties and has good recovery in the arc; the recovery of vanadium is poor. Welded 3% Ni steel has excellent low-temperature properties. To control aluminum and titanium additions, gas welding with special flux is necessary. Holmberg[2] is in general agreement with Chapman and adds that welding rods should have the same composition as base metal. Up to 1% Mo can be introduced through the coating, the molybdenum raising strength and resistance to impact and rust. Nickel, although it improves the yield point and hardness of the weld, tends to thermal check, the micro-cracks probably being associated with air hardening. The effect of air hardening is shown by an anonymous writer.[3] The maximum increase in hardness in the heat affected zone in welding an alloy steel containing, 0.20 C was only 25 Brinell, as compared with 300 Brinell in a 0.45 C steel of identical alloy content. Frequently unalloyed electrodes may be used in welding nickel and other alloy steels because pick-up from the plate metal takes place. Harris[4] states that up to 3% Cr does not markedly increase air hardening; this statement, especially unaccompanied by a statement of carbon limit, is not confirmed by other welding experts. Although chromium-molybdenum steels are easier to deposit than corresponding chromium-vanadium steels, molybdenum has the disadvantage of inducing deep hardening which causes cracks especially in heavy sections. There is no difficulty in welding nickel steels or steels containing up to 3% Cu. With 4% Cu there is a pronounced tendency to cracking parallel to the weld. Larson,[35] who discusses low-alloy steels for pressure vessels, states that welds in 4–6 Cr steel must be annealed, in which case an elongation of 30% in free bend is obtained.

The back-hand method is used by Dawson[5] for gas welding Cromansil and similar steels, because there is more gradual heating and the backward streaming hot gases retard the cooling. For alloy steel pipe of less than $^1/_4$-in. wall, plain carbon rods can be used; torch annealing at 1200–1400° F. is good. The Royal Dutch Marine, according to van Dam,[6] used a steel containing 0.7 Si, 1.2 Mn, 0.4 Cu, 0.10 Mo with a maximum of 0.20% C for their new cruiser; the carbon content was kept low and chromium was not used in order to avoid welding cracks. The German Railways, as Boden[7] states, prefer low-alloy structural steel to medium carbon steel (0.35 C) of the same strength on account of the better weldability of the alloy steel. Hoffmann[8] states that gas pick-up in arc welding depends on the Mn, Al, Zr and V content of the electrode but gives no details. Seven rules for avoiding distortion and cracking in aircraft sheet and tube welding are suggested by Dobson and Taylor[9] who also list the composition of weldable alloy steels. Chromium-molybdenum is slightly easier to weld and stronger than carbon-manganese. Both steels are welded with plain-carbon wire without flux. The Lincoln Electric Co.[10] also recommend a plain carbon electrode for chromium-molybdenum steels of the aircraft type.

Properties

Kliewer,[11] who deals briefly with the gas welding of aircraft steels, shows that Cr-Mo and Cr-Mn-Si steels have excellent strength, ductility and endurance, as welded. Williams[12] in a series of articles outlines the physical properties of welds in low-alloy structural steels, $^1/_2$-inch plate. A steel with 0.20 C, 1.25 Mn shows air hardening but the copper steels do not. To weld a steel containing 0.24 C, 2 Ni, 1 Cu he advises a plain-carbon electrode which may contain 0.4 Mo in the coating. The improvised vibratory hammer test (38 cpm) of silicon steel I beams (0.28 C Avg., 0.25 Si, 1.0 Mn) with stiffening plates intermittently welded to the tensile flanges made by Taylor and Jones[31] was not encouraging. Plain-carbon I beams gave better results. Specimens of steel (0.27 C, 1.20 Mn, 0.24 Si) used in fabricating the towers of the Golden Gate Bridge[40] were tack welded, broken apart and bent at the welds. Other specimens of the steel were drilled and bent until cracks appeared around the drill holes. The broken weld edges bent farther than the drilled holes before cracks appeared. Other plates of the low-alloy steel were tack-welded on the edges, then drilled, riveted and bent. The rivets sheared before any cracks appeared in the welds.

Orr[13] found that tensile and bend results on arc-welded steel containing 0.6 Cr, 0.5 Cu, 0.8 Mn, 0.28 C were satisfactory, but that arc welds in steels containing 0.6 Cr, 1.1 Mn, 0.35 C and 0.6 Mn, 1.9 Ni, 0.19 C did not have good ductility. Possibly his electrodes or technique which he does not describe were not suitable. Tensile, bend, and impact results (impact down to −25° C.) on arc (coated electrodes) and gas welds in $^1/_8$-inch low-alloy steel sheets containing various proportions of Cu, Ni and P are given by Epstein, Nead and Halley.[14] A steel with 0.08 C, 0.5 Mn, 0.13 Si, 0.12 P, 0.02 S, 1.05 Cu, 0.5 Ni showed practically no air hardening and had excellent impact properties. The coating contained 4.6% ferro-molybdenum, which introduced 0.4% Mo into the deposited metal. Although nickel, copper and phosphorus are favored by these investigators, they state that chromium and molybdenum do not have air hardening tendencies if the carbon is kept low. Tensile properties of welds in the copper-nickel steels are given by Nickel Bulletin.[38] See also Meunier and Rosenthal (Appendix I).

Söhnchen and Kleinefenn[15] show that the effect of 3% Ni in bare electrode welds is to eliminate aging and increase notch impact value particularly at elevated temperatures. The general physical properties of the gas and arc (A.C. coated, D.C. bare and coated) welded nickel (2 and 3%) and nickel manganese (2 Ni–1.5 Mn) steels with low carbon (0.04–0.09 C) were not, however, better than plain carbon steel welds. Micromechanical tests (diameter of specimens: 0.06 inch) in tension and shear of specimens taken from all zones of a weld in $^1/_2$-

inch plate of steel containing 0.15 C, 0.9 Cr, 0.2 Mo are described by Portevin and Chevenard.[16] The tensile properties of a number of resistance welded alloy steels are given by Galibourg and Ballay,[32] and an anonymous Italian correspondent[33] has reviewed 53 articles on aircraft welding including spot and gas welding of Cr-Mo steel. Zeyen[34] lists the physical properties of several welded low-alloy steels.

Hopkins[17] shows that arc welded 2¼% Ni steel is excellent for pressure vessels operating at low temperatures. Warner[18] shows that tensile and tensile impact properties of welded plate containing 3½ Ni, 0.35 C are improved 30% and 400%, respectively, by using two passes instead of a single pass at 150 amp, ⅛-inch bare electrode. The effect of stress annealing at 600° C. on the hardness in the weld and junction zones is shown in graphical form for welds in plate containing 3½ Ni and 0.30 or 0.45% C, bare and covered electrodes. He states that welding of structural nickel steels (3½ Ni) with over 0.35 C is not advisable and that the nickel steel welds should always be stress-relieved. In his latest article, Warner presents a table showing the order of acceptability of low-alloy steels for welding purposes based on static and impact tensile properties and the maximum hardness in the heat-affected zone. Hess and Ringer,[19] investigating the magnetic properties of welds, found that the welds in 2% Si steels were best, gas welds having better magnetic softness than arc welds. Steels containing nickel or vanadium were also tested. The profusely illustrated advertising book[20] of a German producer of alloy steel electrodes contains well over 100 photographs of the applications of welded low-alloy and stainless steels.

According to Kinzel[21] the new low-alloy structural steels containing less than 0.14% C have no weld hardened zone; with higher carbon, however, stress-annealing is advisable. McAllister[22] states that a steel containing 0.18 C, 1.45 Mn max, 0.08–0.18 V shows only a small tendency to air hardening, and that Cromansil (0.17–0.25 C) has good weldability. A thorough metallographic study of welded, stress-relieved, and full-annealed Yoloy (0.08 and 0.22 C) is given by Gibson[23] who recommends covered electrodes for maximum corrosion resistance.

Recovery

The recovery of alloying elements during welding has been exhaustively studied by Losana and Jarach[24] whose results are summarized in the following table.

Element	Recovery in % % Element in Weld Metal / % Element in Coating
Nickel (hydrogen-reduced powder)	13.2–32
Chromium (60% ferro-chromium)	9.5–20
Ni-Cr (coating containing 29 Ni, 8 Cr, 7 Mn)	40 (Ni) 37 (Cr)
Tungsten	26.4–47.5
Molybdenum	30.3–42.5
Vanadium	7.25–28.6

By increasing the Mn content of the coating to 30% the recovery of nickel was considerably less efficient; the recovery of vanadium was greatly improved from 7.25% with no manganese to 28.6% with 15% Mn; the recovery of the other elements was not affected to any extent by Mn. Increasing the carbon content of the deposit from 0.04 to 0.69% C also improved the recovery of vanadium. The loss of elements in oxyacetylene welding, as determined by Mercier,[37] is shown in the following table.

Type of Filler Rod	Element	Loss in % Initial Content
1% Mn, 0.4% Si	C	32
	Mn	47
	Si	56
3.5% Ni	C	27
	Mn	29
	Si	50
	Ni	6
0.4% Cr, 0.6% Cu	C	28
	Mn	46
	Si	69
	Cr	5
	Cu	0

The recovery of alloying elements from several types of rail steel electrodes is given by Csilléry and Péter[25] who also study tensile strength, impact, hardness, wear and microstructure of the welds. About 30% of the chromium and tungsten was lost from an electrode containing 1.0 Cr, 1.5 W, 1.15 Si, 1.0 Mn and about 50% of the vanadium from an electrode containing 0.6 V, 1.5 Mn, 0.5 C.

Miscellaneous Steels

According to Lebrun[26] a tool steel containing 8 W, 1.6 Cr, 0.4 Mo, 2.9 Si, 0.3 C may be welded with a coated electrode, the alloy being incorporated in the coating. Jevons[28] illustrates defects in microsections of spot welds between mild steel and spring steel, and resistance butt welds in composite tool steels. Welded-on rivets (mild steel) in 6% W magnet steel always show the fusion line free from interpenetration or alloying, but in 35% Co steel there is marked interpenetration of alloy into the plain-carbon steel rivet. Ziegler and Haughwout[39] give a micrographic study of welds (type not stated) in cast carburizing boxes (65 Ni, 15 Cr, 0.5 C, rem. Fe) after service. In arc welding this material the polarity must be reversed and small beads deposited with frequent peening, using a low-carbon rod of the same composition as the casting.

For welding plow points containing 0.45 C, Sage[27] recommends a gas rod containing 0.3–0.4 C, 0.4–0.8 Mn, 0.50–0.75 Cr, 1.0–1.2 Ni, 0.2 Si which has good scouring action and strength. Ammann[28] describes methods and materials for building up hard surfaces, such as stellite and W_2C, and shows the hardness gradient across the weld in each case. Bliss[29] states that Rutile (TiO_2) acts as an arc stabilizer and may be made to give brittle slags. Rege[30] lists the analyses of coatings of electrodes for nickel, chromium-nickel, stainless and other alloy steels. He finds that acid fluxes consisting principally of pumice, talc and sodium silicate are fluid, form no obnoxious fumes, and produce deposits of better quality than coatings based on lime and calcium fluoride.

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B—Stainless and Related Alloy Steels

An authoritative general review of stainless steel welding is given by Hodge.[1] The low-carbon ranges only of the 4–6 Cr steels should be welded, whether or not W or Mo is present; they should be preheated to 300–400° F. and placed in the annealing furnace immediately after welding. The stainless irons and steels with 12% Cr should be preheated to a high temperature and also immediately annealed after welding, unless 0.07 C or less is present. A steel containing 13 Cr, 1/4% Al needs no heat treatment. The 16 Cr irons are locally preheated and welded with a high-nickel electrode. Microstructure and impact properties are discussed in detail for each group of steels. Another excellent review is given by Nielson[2] who states that the most difficult stainless alloys to weld are those containing 12–30 Cr, the difficulty being in inverse ratio to the carbon content. Plate heavier than 14 SWG is best welded by atomic hydrogen or metallic arc. In arc welding 18–8 the plates are separated 1/16 inch and the current is kept as low as possible.

Dawson[3] states in his review that for gas welding the flame should be neutral as most other writers recommend and the rod should have the same composition as base metal—in 18–8 carbon should be on the low side, nickel on the high side. In arc welding reversed polarity and coated electrodes are used. The flowing qualities of gas rods for 18 Cr iron are improved by adding 1% Si. In common with all other writers on the subject, Dawson finds that columbium is preferable to titanium for 18–8 welding rods, recovery of columbium being much better than that of titanium. Rods of the same composition as the castings are used for high-alloy castings up to 2% C; plain Cr castings are preheated, Cr-Ni castings are not. Houdremont[4] summarizes the welding of stainless by stating that ferritic or partly-ferritic alloys tend to grain coarsening and brittleness near the weld; austenitic alloys are excellent if stabilized; and the martensitic-pearlitic group (13 Cr, 0.3 C) are seldom welded on account of air hardening. Gas welding the stainless steels requires a flux unless over 40% Ni is present. The electrode is positive for arc welding; 12–30 volts, 40–150 amps. depending on plate thickness Karsten[5] states. The stabilizers mentioned are titanium, zirconium and tantalum.

The gas welding of 18–8 is generally said to be much the same as for mild steel,[6] except that the neutral flame is somewhat smaller and a special flux is required to reduce chromium oxides. Keel[7] advises that 0.04-inch sheet be tacked at 3/4-inch intervals, 0.08-inch sheet at 1 1/2 inch intervals; the edges are first smeared with waterglass, then powdered borax and boric acid is sprinkled on. Back-hand welding is used above 0.06-inch sheet. The application of water-soaked asbestos strips to surfaces exposed to the flame is suggested by an anonymous writer[40] to prevent warping during the gas welding of 16 gage stabilized 18–8.

Biernacki,[8] who adopts the welding methods recommended by the International Acetylene Association, states that cutlery type stainless and unstabilized 18–8 require heat treatment after welding but that the 25 Cr-20 Ni type does not. According to Priestley,[9] the 4–7% Cr steels should be gas welded with a rod containing 6–8 Cr and about 1% Cb; the weld may then be torch annealed 1–2 minutes at 1475–1650° F. Whatever stabilizer is used in the base metal, columbium should be added to the rod. A small amount of silicon may be incorporated in the rod, as Kinzel[43] points out, to protect columbium from oxidation.

In a general discussion of 18–8 welding by all processes, Hanel[45] states that above about 20% reduction in cold rolling spot-welded 18–8 has lower tensile strength than cold-rolled base metal. The following data are supplied by Krupp:

Gas Welding 18–8			
Plate Thickness Inch	Nozzle Opening Inch	Gas Consumption Liters/Hour	Max. Oxygen Pressure Atm.
Up to 0.06	0.02	33	0.50
0.27 to 0.40	0.07	480	1.50
D.C. Arc Welding 18–8			
Plate Thickness Inch	Electrode Diam., Inch	Voltage	Current, Amp.
Up to 0.08	0.08	25–30	20–40
0.20 to 0.24	0.24	25–30	170–240

Welding with A.C. is more difficult than with D.C. Lee[47] states that nitrogen does not impair the weldability of 18–8 and that Si actually improves it.

Grismer[10] points out that a slight excess of oxygen makes a welded joint in 18–8 hard and unmachinable and states that a protective gas should be used in arc welding. Detailed instructions for grinding and polishing welded joints in 18–8 are given. The tensile strength of gas-welded 18–8 aircraft tubing, according to Hoffmann[11] is 92,000–107,000 psi with or without 1.3% Ta, the strength of welded low-alloy chrome-molybdenum being 90,000–102,000 psi. The ratio of fatigue limit welded to fatigue limit unwelded of oxyacetylene welded 18–8, and gas and flash welded Cr-Mo aircraft tubing is as low as 0.39 without heat treatment and as high as 0.96 heat treated, according to Johnson.[35] Henry[44] found little difference in tensile impact value of gas and arc welds in 18–8 between +20 and −80° C.; the welds were about 30% less strong and ductile than unwelded. In arc welding 18–8, 2% Cr and 0.5% Ni are lost, Mitchell[12] states, and this loss must be allowed for in the electrode. His statement concerning the efficiency of columbium is in agreement with the recommendation of Pratt[13] and Jones.[14] A. P. Johnston[15] deals with all phases of arc welding 18–8. The short arc reversed polarity eliminates pin holes, 20–30 volts being best: 125–200 amps. for sheet 1/8 inch and over using 3/16 inch electrode. Tacking, clamping and step-back welding are means of avoiding distortion. Vertical welds are never made downward. Auribault[36] also gives hints for welding 18–8 and 13 to 18% Cr irons. According to Ragsdale,[38] single-lap shot-welded 18–8 joints can easily develop 85% ef-

ficiency compared with 60% for good riveted connections. The only practical consideration that makes shot welding of 18–8 practicable is that welding pressures (often more than a ton for a $^1/_4$-inch weld in two 16 gage sheets) can be used sufficient to draw the sheets together without breaking the surface scale. The stress distribution in shot-welded seams is a matter of uncertainty, the sheets being hard and the spots soft. In spot welding, Ruppin[16] points out that the low thermal conductivity and high electric resistance of 18–8 require short welding times. Ross[17] and Gillette[18] describe the spot welding of the 18–8 evaporator units manufactured by the General Electric Co. Wrana[19] describes mechanical and electrical tests of welds in nichrome and kanthal made by the condenser-discharge process.

The arc welding of stainless-clad materials is also discussed by Johnston. He recommends a 25 Cr-12 Ni electrode of a larger diameter than for a like gage of straight 18–8, because the base metal has a higher heat conductivity. For 25–12 and 18–8 overlays the technique, once acquired, solves all problems. Poste[20] states that stainless-clad is more difficult to weld than nickel-clad, the iron pick-up being more injurious in the former. According to an anonymous writer,[21] the 18–8 side should be welded, reversed polarity, with a flux-coated electrode containing 24 Cr, 12 Ni, low carbon. The current should be as low as possible consistent with penetration, and peening or heat treatment is unnecessary. Keelor,[22] Schöne,[37] Trautmann[39] and Schafmeister[22], also give practical details and test data on welding mild steel clad with 18–8. The difficulty in welding 18–8 to mild steel lies in the difference in contraction coefficient, according to Child[23] who shows that cracking may be avoided in welding an 18–8 disk into mild steel if the disk is first welded to a mild steel ring.

Although American practice in welding 18–8 appears to favor the addition of columbium for stabilizing, the columbium-carbon ratio depending on corrosive conditions, English practice, as recently outlined by Monypenny,[24] relies upon stabilizing additions of silicon up to 6% or molybdenum up to 4%, neither type of alloy requiring heat treatment after welding. Bull[25] also states that 1.5–2.0% Si with 3–4% extra nickel overcomes weld decay in 18–8. According to Dobson and Taylor,[26] English aircraft stainless steels are gas welded without flux using a wire containing 24–28 Ni, 15.5–19 Cr, 2–3.5 Si, 0.6–1.25 Mn and 0.25–0.55 C. The flame must not be oxidizing and should have as little excess acetylene as possible. If reverse welding is necessary the root must be descaled. Grimshaw[27] states that 18–8 containing 4–6 Mn, 3 Cu and 0.1 C has good weldability. Internal stresses accelerate weld decay in 18–8, according to Rollason,[28] who deals entirely with the microstructure of welds in 18–8, not with weldability. According to Whitney,[29] the M. W. Kellogg Co. tests the welding qualities of high-alloy stainless steels by noting the shrinkage cracks and distortions in a small test vessel designed to exaggerate shrinkage effects. All-weld-metal bars are subjected to the Huey test (65% boiling nitric acid) or to 3% copper sulfate—10% sulphuric acid for 72 hours and then given a bend test. A study of the microstructure, tensile properties, and hardness of welded stainless iron and steel has been made by Sasaki[30] and the weldability of Cr, Cr-Si-Al, and Cr-Ni steels has been investigated by Marke.[46]

The welding of high-chromium heat-resistant steels is possible by all processes except forge and water-gas, according to Schottky[31] who shows that such steels should not be welded with high-manganese electrodes if attack by hot, high-pressure hydrogen is to be prevented. Hinde[41] states that the heat-resisting qualities of welds in heat-resisting steels are the same as base metal. The plain Cr heat-resisting steels are the most difficult to weld. Covered austenitic electrodes with high silicon content are recommended by Czyrski[42] for heat-resisting steels. Thum[32] states that the 5% Cr steels air-harden to a considerable degree and must therefore be preheated, and after welding, immediately annealed. On the basis of experience and microstructural examination, Rapatz and Hummitzsch[33] state that nickel austenitic weld metal gives a tougher transition zone with mild steel than manganese, and that chromium and molybdenum improve the weldability of austenitic steels but have much less effect on the microstructure than nickel or manganese. The Krupp austenitic electrode for welding plain-carbon and other steels has been described in a number of articles.[34] The 25 Cr-20 Ni electrode is used for welding non-aging boiler steel, plain-carbon steel up to 0.7% C, Silchrome (8 Cr, 3 Si), and medium-carbon nickel-chromium, chromium, chromium-molybdenum and 3% nickel steels. For arc welding the electrode may be coated.

Additional references on stainless steel welding are given in a review on the behavior of welds in special materials under corrosive conditions, prepared by the committee.

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C—Alloy Steels at British Welding Symposium

This review is intended to serve both as a summary of, and as an index to, the contributions on alloy steel welding at the Welding Symposium held by The British Iron and Steel Institute in 1935. For the sake of convenience in reference, the contributors are dealt with in this summary in consecutive order, the papers of Volume I being abstracted first. The pages corresponding to each contributor's work are noted in parentheses after his name; an asterisk signifies that the entire paper deals with the welding of alloy steels.

VOLUME I

Arvidsson, D., 31–42. To obtain a specified ductility in welds in steel containing 0.2 C, 1.0 Mn, 0.7 Cu, 0.5 Cr, 0.1 Ni, electrodes of lower strength steel had to be used.

Hopkins, R. K., 243–258. Tests, particularly at low temperature, of welded specimens and pressure vessels of $2^1/_4$% Ni steel are described.

Inglis, N. P., and Andrews, W., 259–265. Heat treatment is absolutely necessary for welded alloy steels; ingotism in the weld can only be removed by hot work. Tungsten and molybdenum are suggested for preventing weld decay in stainless steels.

Jasper, T. McL., 267–272. Steels with up to 3.8 Ni, or Cr-V with 1.1 Cr., as well as 16–18 Cr-iron and 18–8 have been successfully welded.

Ross, D., 289–298. Water gas welding of molybdenum steel (0.4% Mo) for pipes is successful up to $1^3/_4$-inch wall.

Ashworth, J. M., and May, H. N., 299–306. Arc welds in rails containing 0.7 Mn, 0.3 Cr.

Strelow, W., 426. Cored electrodes containing 3% Mn are satisfactory; in bare electrodes, 3% Mn causes marked disturbances of the arc.

Johnson, J. B., 433–441. (See also AMERICAN WELDING SOCIETY JOURNAL, **14,** (8) 14–18, 1935 **15** (9) 2–11, 1936.) Chromium-molybdenum steels of the aircraft type have air-hardening properties which counteract the softening effect due to the welding heat in the junction zone. Filler rods containing $3^1/_2$ Ni or Cr-Mo are sometimes used for Cr-Mo tubing but usually an unalloyed low-carbon electrode is used. In order to obtain high ductility in welded chromium-vanadium steel propellers, the atomic hydrogen process is used.

Roosenschoon, J., 443–448. The Fokker plant uses little Cr-Mo tubing because air hardening causes cracks after welding. All 18–8 sheet must be accurately fitted and beveled before welding, which is not easy (0.028–0.047 inch) and requires a neutral flame.

Sutton, H., 449–458. Corrosion-resistant steels are welded with rod of the same composition, and the welds may be quenched and tempered or simply tempered. Iron or Cr-Mo rod is used for Cr-Mo tubing (0.27–0.32 C, 1.0 Cr, 0.19–0.27 Mo, 0.4–0.5 Mn); it is not so easy to weld as mild steel. Welding the 12–13 Cr steels is made easy with a rod containing up to 0.55 C, 28 Ni, 10 Cr, 3.5 Si which has excellent fluidity. The atomic hydrogen process appears to produce much sounder welds than gas but is still in the experimental stage at Farnborough. Tables of physical properties are given for stainless tubing as welded and heat treated. Samples of 12 Cr, 0.15 C (1-inch tube 16 G) gave only 2.5–9% elongation in 2 inch when failure occurred in the weld (56,000 psi). Samples of 16–20 Cr, 2 Ni, 0.2 C gave 8–14% elongation and 92,000 psi. tensile. Research on welding alloys teels is now in progress at Farnborough.

Taylor, R. F., 459–464. Chromium-molybdenum tubing (not over 0.25 C) is easier to weld and stronger than unalloyed low-carbon or carbon-manganese.

Wrightson, P., and Warriner, R., 605–608, had no difficulty in welding low-alloy structural steels.

Fletcher, J. E., 621–628.* Wrought iron.

Andrew, J. H., and Johnson, W. A., 503–506.* Wrought iron.

Nápravník, W., and Popov, S., 513–526. Wrought iron.

Pollard, F. E., volume 2, 825–829. Wrought iron.

Pearson, V. G., 629–634. Electrodes for alloy steel castings should have the same compositions as parent metal.

VOLUME II

Shepherd, T. C. R., and Carpenter, S. W., 161–179. Steel high in silicon has a high liquid-to-solid contraction and often cracks down the center of the weld.

Brillié, J., 213–222. In France, steels up to 85,000 psi are successfully arc welded.

Spraragen, W., 251–261. The Watertown Arsenal is studying the welding of nickel and molybdenum steels.

Andrews, W., and Welsh, W. C., 307–316.* Low-carbon steel with 0.25–0.50% Mo or V is successfully water gas welded with a flux to remove scale. The oxyacetylene and atomic hydrogen processes produce good welds in this type of steel and developments in arc welding this steel are expected. Stainless and 18–8 are susceptible to burning (micrographs). With the exception of metallic arc, oxyacetylene and atomic hydrogen, all other processes have obvious disadvantages for welding alloy steels. Steels with high chromium and low carbon are less severely affected by welding than other corrosion- and heat-resistant types.

Atkins, E. A., 317–320. Mild steel gas welding rods should not contain over 0.04% S or P. Both carbon and manganese are usually higher in electrodes than in gas rods. The presence of 0.14% P in mild steel plate has been known to cause brittle welds.

Chevenard, P. A., and Portevin, A. M., 333–352,* give results of micromechanical tests in welded (gas and covered electrodes) Cr-Mo (1 Cr, 0.36 Mo, 0.28 Ni, 0.31 C) and 18–8. Shear tests in the former steel reveal a zone of low strength about 3 inch from the weld ($^1/_2$-inch plate) in gas but not in arc.

Deglon, C. R., 353–359,* presents hardness and microstructural study of rail surfacing deposits (flux-coated electrode containing 1.0 C, 1.2 Cr, 0.7 Mn; deposit containing 0.4 C, 0.7 Cr, 0.6 Mn). Preheating to 400° C. is recommended.

Hatfield, W. H., 363–371.* *Iron Steel Ind. British Foundryman* **8,** 311–313 1935. In general silicon is not good for the weldability of low-alloy steel. Nickel is not detrimental but welds in 3% Ni steel should be stress relieved. Chromium is like nickel but the oxides must be taken care of by a flux. Molybdenum up to 0.7% is without effect on welding properties. Aluminum steels are not welded by the metallic arc. Tungsten and titanium overcome the carbide question in 18–8.

Helin, E., and Svantesson, S., 373–390 (see also Helin, E. *Teknisk Tidskrift,* **65,** 75–83 1935, in which the impact value of $^1/_2$-inch butt welds in 0.6 Cr-0.5 Cu steel is 12.45 mkg./cm.^{2} Charpy, and for low-carbon steel butt welds only 9.27 mkg./cm.^{2}). For welding low-alloy structural steels a neutral slag is not safe because fillet welds then tend to crack.

Moritz, M. R., 445–452, deals with stainless irons and steels. Usually the electrode is given a spiral wrap

of white or blue asbestos yarn and then coated with a flux containing cryolite, calcium carbonate or fluorspar to dissolve chromium oxides. The 18 Cr alloy is welded with a 19.5 Cr electrode. The atomic hydrogen process has universal application but the metallic arc is good only up to 13 Cr and for 18–8. The atomic hydrogen process is always preferable but gives more distortion. The metallic arc can be used only down to 0.07 inch sheet but the atomic hydrogen process can be used down to 0.03 inch. For vacuum tightness the atomic hydrogen process must be used. Welded 18–8 should contain titanium (up to 1%) with or without tungsten. In welding clad steel the bottom of the V, which is in the clad side is filled with stainless alloy; then mild steel is deposited to complete the weld, heat treatment usually being unnecessary.

Pearce, J. G., 463–470, discusses the welding of Niresist and Nicrosilal cast irons.

Portevin, A. M., and Leroy, A., 475–481.* Silicon forms a protective coating over the molten metal resisting the loss of volatile elements. There is no definite relation between the chemical composition of all-weld-metal and of a weld made with the same electrode.

Portevin, A. M., and Séférian, D., 483–506. Nitrides.

Hodge, J. C., 391–417. Nitrides.

Rapatz, F., 507–516.* To prevent the formation of a martensitic transition zone between austenitic weld metal and mild steel plate, the composition of the electrode should lie well within the gamma region and should be low-carbon. In this way the transition zone consists of a mixture of ferrite, austenite and tough martensite.

Reeve, L., 517–529. The high temperature of the arc probably puts the oxides of Si, Mn and Al into emulsion, if not into solution in the molten metal. Nitrides.

Shepherd, T. C. R., and Moritz, M. R., 561–567. The terms acid and basic applied to fluxes refer to their action on the silicon content of the filler rod. If silicon is absorbed by the flux, the flux is basic; if flux is reduced it is acid.

Streb, E., and Kemper, H., 573–591.* Phosphorus up to 0.10% is not harmful in gas welding, but should be kept preferably below 0.05%, as cold bend and tensile tests show. Unless it is segregated, sulphur up to 0.04% is harmless. About $^1/_2$ of the nickel was lost during welding from gas rods containing 0.11 C, 1.4 Mn, 0.5 Ni. For low-alloy structural steels, gas rods containing $3^1/_2$ Ni, or 2.1 Ni, 0.14 Mo are recommended from the standpoint of physical properties.

Swinden, T., 600. Careful tests in which all other variables were held constant failed to reveal any differences in welding qualities between hard drawn and annealed filler rods.

Thum, E. E., 603–616,* presents some notes on high-Cr steels:

1. Gas welding thin stainless sheet with neutral flame or atomic hydrogen;
2. Metallic arc is used for sheet $^3/_{16}$-inch thick or over, using carbon-free coated electrodes; the slag is made up of lime, silica, clay, cryolite, etc., with sodium silicate as binder, ferro-manganese, ferro-titanium or aluminum being incorporated; the following elements are completely recovered during welding: Ni, Mo, W, Cu, Mn and Si;
3. Spot welds;
4. Repair of high-alloy castings with a coated electrode containing up to 29 Cr–9 Ni or 35 Ni–15 Cr;
5. Clad sheet.

Zeyen, K. L., 617–633, discusses rods for built-up welding including 12% Mn, and 0.55–1.12 C, 1 Cr, 1.5 W.

Martin, W. H., 647, mentions a low-alloy chromium—aluminum heat-resisting steel: Sicromal made by a German tube works and having excellent non-hardening welding qualities (no details).

D—The Modulus of Elasticity of Austenitic Welds in Mild Steel

The austenitic welding process recently patented by Krupp raises a new the question of the mutual action of two materials with different moduli of elasticity, as in brazing and soldering. In the Krupp process non-aging mild steel (Izett steel containing 0.25 C, 0.5 Mn, 0.05 Si, 0.01 P, 0.106 S, trace of metallic aluminum) is welded with a Nicrotherm electrode of the following analysis:

	C	Si	Mn	Ni	Cr	N_2	O_2
Electrode	0.09	0.78	1.31	19.9	25.2	0.019	0.040
Deposited Metal	0.20	0.35	1.86	18.4	22.3	0.044	0.050

Although the deposited metal has the same coefficient of expansion as mild steel, the austenitic weld metal has a much lower modulus of elasticity, about 21×10^6 psi. The importance of this difference was noted by several members of the AMERICAN WELDING SOCIETY to whom Dr. E. Beckmann, technical director of Krupp's, supplied additional information.

"The Nicrotherm electrode, rolled structure, has a modulus of elasticity of 27.0 to 28.5×10^6 psi before welding. However, welding changes the microstructure and modulus of elasticity, the modulus in the longitudinal direction of the weld being 21.4 to 22.8×10^6 psi. Transverse to the weld seam there is no general value for the modulus on account of the effect of plate thickness, shape of seam and other local conditions."

The low modulus is explained by Dr. J. C. Hodge of the Babcock and Wilcox Co. as due probably to the dendritic structure and strained condition of the as-deposited weld metal. Both factors tend to produce deviations of the stress-strain curve from Hooke's Law at low tensile stresses, e.g., 15,000 psi. These deviations lower the apparent modulus of elasticity. An example is Cyclops No. 17 metal (0.4 C, 1.0 Si, 0.8 Mn, 20 Ni, 8 Cr) whose modulus is 20×10^6 psi as cast but 28×10^6 psi after forging or rolling. The practical significance of the difference in modulus of elasticity between weld metal and plate depends on the type of stress. If the weld is transverse to the axis of stress, the weld metal undergoes greater deformation in tension or compression than the plate (1.4 times as great in the austenitic weld, larger in brazed or soldered joints), which may tend to cause leakage or other effects depending, as Beckmann points out, on local conditions. If the axis of load is parallel to the axis of the weld, the plate metal withstands 1.4 times as much elastic stress as the weld metal. The effect of these factors on shrinkage stresses and stress concentrations is incompletely known.

APPENDIX V

Recent Literature on Non-Ferrous Welding

A—General Non-Ferrous Welding and Nickel Welding

General

An introduction to the subject of non-ferrous welding is afforded by Hignett's recent review.[1] He lays chief

emphasis on the importance of a constant supply of high-pressure oxygen and acetylene for non-ferrous welding. He describes several approved methods for valving and distributing the gas supply and unconditionally condemns the injector blowpipe. Rightward welding is better than leftward, especially from the standpoint of the fatigue of the welder. The oxy-hydrogen and oxy-coal gas processes are still useful for aluminum and lead, but their chief disadvantage is the water vapor evolved. Hignett is not enthusiastic about carbon-arc welding, which produces oxidized welds unless controlled by bulky equipment. Recent developments in arc welding, particularly aluminum, are discussed, but the process is said to require a born welder and good electrodes and fluxes. The trend in spot welding is toward very high current densities and short times: $^1/_2$ to 1 cycle, transformers of considerably greater capacity than for mild steel being required. For materials of high electric conductivity, tungsten-copper or beryllium-copper electrodes are recommended with as low initial contact pressures as possible. Machines utilizing condenser discharge or the accumulated energy principle appear very promising. Hignett states that commercial spot welds always contain evidence of fusion. Attempts to flash weld aluminum and its alloys, and copper have been unsuccessful and the only method of welding practicable for magnesium is the blowpipe.

Unfortunately, a good deal of Hignett's article applies only to English conditions, but nothing of equivalent scope has been published elsewhere. Lüder and Heinemann[5] discuss the significance in welding of the following factors: Thermal capacity and conductivity, solidification interval of base metal and filler rod, oxygen affinity, and solubility of gases, principally in connection with Cu, Al, Fe and solders. It is suggested that the weldability of a new alloy by a given process may be predicted on the basis of a study of the above factors. White[2] reproduces a chart showing the spot weldability (good, brittle, poor or no weld) of 250 pairs of metals, mainly non-ferrous. Meller's handbook[3] contains ten pages on the practical aspects of non-ferrous arc welding, and Schimpke-Horn's text-book[4] lays down the general rule that in all non-ferrous arc welding the electrode is positive, except in carbon-arc welding.

Nickel and Its Alloys

According to Henry Wiggin and Co., Ltd.,[10] the gas welding of nickel and Monel should be done with a slightly reducing flame with boric acid as flux. Arc welding is impracticable below 18 G; electrodes should be coated, positive, and should be a little larger in diameter than the thickness of the sheet. In spot and seam welding the main precaution is to keep the electrodes cool to prevent oxidation. The corrosion resistance of welds is as good as parent metal and there is no weld decay. For gas welding nickel and Monel, Flocke and Schoener[11] state that rods should be annealed, free from oxides, and should have the same analysis as the plate. In order to avoid burning the deoxidizing agent, the flame should be slightly reducing and the bath should not be puddled. Flux is always used with Monel but seldom with nickel. A heavy-coated shielded arc electrode (positive) is used for both metals. Mayer-Sidd[24] briefly describes the A.C. arc welding of nickel using a new type of Griesheim electrode. Tensile tests were made on 70° V butt welds, root spacing 0.018 inch.

Boutté[12] states that the flame must be strictly neutral for nickel and that difficulties are overcome by adding Mn or Mg. The rule: $(Mg-0.02)/S = 4$ 4 to 5 is given, where Mg and S are the percentages of magnesium and sulphur in the plate or rod. Silicon should be 0.15 to 0.20%, and a flux is necessary to avoid loss of Mg. Borax is recommended as a flux for Monel and a stainless flux is best for Inconel. An anonymous French welder[13] states that rightward welding with powdered flux is best and that plate and rod must be free from sulphur. The burner should pass 100–150 liters of acetylene per hour per mm. thickness of plate. Modro[14] found that gas welding is facilitated if the nickel contains titanium or the rod contains silicon. Modern practice in arc welding nickel, according to Harris,[15] favors slag-coated electrodes containing aluminum and ferro-titanium. Great care must be used in multiple layer welding to avoid cracking of the first layers. Good physical properties are apparently not to be expected although peening is beneficial. Keel[16] also observed the benefits of peening and recommends fluxes composed of boron compounds. Forehand welding is used up to 0.04 inch plate thickness, above this backhand is best.

The welding of nickel-clad mild steel is described in detail by Huston and Watson.[17] After laying down the mild steel weld and chipping out the root a pure nickel electrode is used with short arc, $^1/_{16}$ to $^1/_8$ inch, 100 amps. for $^1/_4$ inch plate, 150–200 amps. for $^1/_2$ inch. Details are given for overhead welding and inside fillets. Special flux-coated rods must be used for carbon-arc welding. In gas welding the flame must be slightly reducing, the tip being one size larger than for similar work on mild steel. Peening is always desirable. Poste[18] states that the chief difficulties in welding nickel-clad steel are gas absorption and porosity which are overcome by peening. The iron content of the Ni layer in butt welding nickel-clad steel is usually between 0.5 and 7%, according to Trautmann.[23]

Inconel welding is discussed by Boutté.[19] A weak neutral flame, 50–75 liters of acetylene per hr. is used, the filler rod having the same analysis as plate. A patented flux (no details) is said to prevent the oxidation of chromium. Welds in sheet from 0.024 to 0.12 inch have the same strength as parent metal but elongation (% in 2 inches) is 36% welded, 50% unwelded. Inconel is very brittle in the range 700–800° C. For plate over $^1/_8$ inch thick arc welding may be used, special coated electrode, D.C., reversed polarity. In arc welding fractures the electrode is given a circular movement and the arc is repeatedly extinguished by quickly dipping the electrode in the molten bath and withdrawing it. In gas welding Inconel the acetylene pressure, Milne[20] states, must be constant; each operator should have a separate acetylene tank. Durglund[21] describes the gas welding of preheated Monel to cast iron using a cast-iron rod and Brazo flux, and Muller[22] gives a brief review of current practice in welding Monel.

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B—Zinc and Lead Welding

Horn[1] has given the most complete account of recent progress in zinc welding. The oxyacetylene flame with 10% excess oxygen (according to his earlier paper, but strictly neutral according to his later article) is satisfactory for sheet up to $^1/_{10}$ inch thick. Zinc strips with a powdered flux were better as filler material than flux-cored rods, the flux being a mixture of NH_4Cl and $ZnCl_2$. The torch should pass 50–60 liters of acetylene per hr. per mm. thickness. There seems to be no preference between back-hand and fore-hand welding. Welds are made up of large grains but X-rays show no defects and welds have 90–100% of the tensile strength of base metal. The grain is refined by light hammering at 150° C. Peters[2] states that for thin zinc sheet the blowpipe flame should have a slight excess of acetylene, the filler rod being pure zinc fluxed with sal ammoniac. A brief note[3] in a Swiss welding magazine recommends that zinc welds be annealed at 150° C. to remove brittleness and that the torch should pass 50–100 liters of acetylene per hour. Workshop methods are discussed in another unsigned article.[4]

Zinc-base Die Castings

The repair of zinc-base die castings is fully described by Mace,[5] who considers castings containing 0–7.5 Al and 0–5 Cu. Preparation is the same as for aluminum and veeing is recommended for thicknesses of $^3/_{16}$ inch and over. The parts to be welded are rigidly held; the parts near the weld are covered with wet or dry asbestos paper, wet if the casting may totally collapse when heated. The size of torch nozzle is somewhat smaller than for steel. The flame should be soft with a slight excess of oxygen, but not so much as for bronze welding. Heating is slow to avoid splashing when the oxide films burst, and puddling is necessary. The angle between torch and deposited metal is 45 to 60°. The filler rod should have the same composition as the casting but with a slight excess of zinc, although there is little loss of zinc by evaporation. Percival[6] advises that the flame for welding zinc-base die castings should have a slight excess of acetylene, that no flux should be used, and that the torch should be small, the same size used for lead. Sage[8] also uses a soft carburizing flame, 2 inches long, with small tip. The filler rod is applied to the fracture when small beads appear on the preheated surface. The carbon arc is used for heavy die castings. According to Raymond,[7] the air-acetylene flame is best for zinc-base die castings.

Lead

An excellent survey of lead welding, including historical development of gas welding processes is given in a German welding magazine.[10] Overhead welding, the welding of battery plates, lead coatings, and the welding of chemical apparatus for sulphuric acid are among the topics discussed. According to an anonymous Swiss article,[11] filler rod and edges to be welded should be shaved clean just prior to welding. The burner capacity should be 50 liters of acetylene per hour. Plates up to $^1/_4$ inch are overlapped. The following topics are discussed: Methods of vertical welding by holding a mold over the joint, methods of weaving, fillet welding and overhead welding. Schulze and Staebler[12] recommend a small high-pressure type oxyacetylene torch to give good flame control, instead of the usual oxyhydrogen torch, but Korta[13] believes that the latter method is best for lead if his new type of torch is used. Rogers and Carter[16] describe the weaving movement that must be given to the torch in lead welding and state that a 30° V should be used for plate over $^3/_{16}$ inch thick. Detailed instructions are given by Adams[14] for gas welding lead cable sheath, a process known as duct splicing. The total length of the flame should be 5 to 6 inches, the hottest part being $1^1/_2$ inches from the tip. An anonymous writer[15] gives full instructions for coating tinned steel with lead by means of an oxy-gas blow pipe.

Other Metals

Antimony is welded like lead[20] using a weak flame and no flux. The flame is held $^1/_2$ inch to 1 inch away from the metal so that only the tip plays on the surfaces to be welded. Annealing is recommended. Tantalum is welded while it is immersed in carbon tetrachloride, according to the Lincoln Electric Company.[21] A carbon electrode is used which draws 60 amps. at 50 volts for 0.001 inch sheet. Tantalum wires are spot-welded through a thin separating layer of nickel; the nickel is completely alloyed during fusion.

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C—Aluminum Welding—General

In view of the large number of good recent articles on the various aspects of aluminum welding, the subject has been divided into three parts: general, processes (including gas, arc and resistance), and alloys and castings (welding and repairing). The "general" section deals with comprehensive articles on many phases of aluminum welding, subdivision of which would be scarcely worth while. Comments from two reliable foreign sources suggest that our own country is not keeping pace with others in aluminum welding, at least so far as publications show.

Among the most complete articles on aluminum welding are two by Buchholtz.[1] The mechanical properties of gas and hammer welds are about the same but the corrosion resistance of hammer welds is not so good as gas. Oxyhydrogen welds are more brittle than oxyacetylene on account of the solution of hydrogen in the former. The tensile strength of the untreated

weld is only 50% of parent metal in both processes. The zone of large grains on each side of a weld in hard-rolled sheet is prevented by jumping up the edges before welding so as to produce critical deformation and consequent fine-grained recrystallization after hammering and annealing. He mentions a special filler rod that gives fine grain without after treatment but gives no details. Welding of heat treatable alloys is not recommended. Buchholtz emphasizes that hot shortness in casting alloys, particularly Silumin, is a consequence of eutectic formation and must be borne in mind in repairing castings.

According to Eyles,[2] the processes principally used are resistance and oxyacetylene, occasionally the oxyhydrogen. For spot welding water cooled copper electrodes are used; the water cooling prevents alloying. The tensile strength of untreated gas welds is 40 to 60% of the parent plate; after hammering at 300° C. it rises to 75–90%, fracture occurring in the transition zone. Flux is best applied as a thin varnish on the gas rod, which should have the same analysis as parent metal but slightly larger in diameter. Above $^1/_8$ inch the edges of the plate should be beveled; the torch is inclined 35 to 40° to the plane of the weld.

Douchement[3] states that gas rods should have the same composition as the plate, except for pure aluminum when 0.15% Ti may be added. For alloys with a low melting point eutectic, the 5% Si alloy is used. A lengthy table of physical properties of gas welds in Al; Dural; 7% Mg; 4% Si and others is given. In arc welding the arc should be as short as possible; $^1/_8$–$^3/_{16}$ inch, and a resistance of $^1/_3$ to $^1/_2$ ohm is put in series to increase stability. A table of times and currents is given for spot welding Dural. Butt and flash resistance welding is facilitated by interposing a thin sheet of Al (0.012–0.016 inch) between the ends to be welded.

Hermann and Zurbrügg[4] give complete data on gas welding (apparatus, fluxes, weld treatment) and on welding different shapes. Rostosky[5] traces the historical development of welding processes for the light metals and defines a joint as a weld if deposited metal and parent metal are chemically homogeneous. Welding aluminum with a 5% Si rod is therefore hard soldering. The general practice in Germany for welding pure Al is to use a filler rod containing titanium. Zimmermann[19] recommends that corner, lap and fillet welds in Al be avoided on account of their low dynamic properties. Although cold hammering decreases corrosion resistance, hot hammering improves mechanical properties without decreasing the corrosion resistance. Aluminum may be hammer welded above 400° C. (although the lower limit for alloyability, according to other work, is 250–300° C.). Puddle welding is now used only for repairing silumin castings. The zinc-foil and casting-in processes are rarely used for electron. A brief review of problems in arc, spot, seam and butt welding structural alloys is given by Bohn.[6]

Haarich[7] found that the gas (N_2-H_2-CH_4-CO) content of welds in 99.35% Al, $^3/_{16}$ inch and $^1/_2$ inch thick by arc and gas processes (including O_2-H_2, O_2-C_2H_2, Arcogen, D.C. and A.C. arc) was greater than in parent plate, the junction zones with gas welding having the highest gas content. A mass of data on strength, hardness and elongation of welds made by these processes is presented. In general, A.C. and D.C. gave the highest strength (15,600 arc, 12,800 gas) and the lowest elongation (19% arc, 30% gas). Hammering cold raised to strength 10% but lowered elongation up to 50%. Annealing after cold working gave better ductility than untreated and equal strength. Corrosion resistance was greater in acetic acid than in sulphuric; in the latter the weld was preferentially attacked. The recrystallized zone near the weld was more resistant than parent metal. Cold hammering raised the corrosion velocity up to 20% (15 days, machined specimens) but subsequent annealing lowered the velocity below untreated welds.

The methods of welding, physical properties, and microstructure of joints of aluminum with iron, copper, brass, nickel, monel, stainless steel, lead and zinc, are given by Holler and Maier.[8] In most cases the heavy metal was tinned. Lux[9] describes methods of welding aluminum high-tension cables using special clamps. The fatigue strength (no details given) of resistance welded joints in aluminum alloys is equal to that of riveted joints, according to Schulze[10] who also outlines the fields of application of arc and gas welding. Fuss[11] gives brief notes and a short bibliography on the microstructure of aluminum welds. Rohrig and Nicolini[12] place the upper limit for spot welding at 0.08 inch, and show that HNO_3 may penetrate completely along a hammer welded seam in aluminum tubing. Local annealing raises the corrosion resistance of the gas-welded or peened seam. They state that aluminum can be more quickly gas welded than copper. For gas welding Warrington[13] uses excess acetylene and a flux consisting of alkali chlorides and a little cryolite. The filler rod should have the same composition as the alloy but slightly higher silicon to increase fluidity and soundness. The arc is generally less suitable than gas but is good for repairing large castings.

The oxyhydrogen process may be used up to $^5/_{32}$ inch plate for thicker plate the oxyacetylene process, according to Gentzcke.[14] Hot hammering raises the tensile strength of welds in KS Seewasser to 30,000 psi, 9% elongation. Hammer welding is carried out by heating to 450–500° C. in a furnace or with a soldering torch and then hammering together. For lautal and some other alloys on aluminum foil (0.004–0.012 inch thick) must be placed in the joint before hammering. In welding aluminum aircraft parts Dobson and Taylor[15] use wire of the same analysis as plate or 8–9% Si rods for castings, and a flux conforming to British Aircraft Specification DTD 119. They find duralumin difficult to weld but magnesium is easy using the same flux as for aluminum and a strip of parent metal for welding rod. Alclad, 18 gage, spot welded with contactor control develops 951 lbs./spot in double shear. Hartmann[18] states that, although welding is excellent for low-strength Al alloys, it has not developed to the stage where it may replace riveting in structural Al. General reviews of the applications of aluminum welding are given by Osten and Maier.[16] Extensive data on the elastic properties, modulus of elasticity, and hot-shortness of aluminum alloys at elevated temperatures are given by Vero;[17] these may be found to apply to welding problems. Measurements by Buser[20] of the electric conductivity of Al bus-bar (0.28 × 0.40 inch) with 11 welds in a 10 ft. length showed a decrease of 1.2% in conductivity.

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D—Aluminum Welding—Processes

Gas

The Aluminum Company of America[1] state that oxyhydrogen and oxyacetylene are the best welding processes for aluminum and its alloys. Their booklet contains a number of practical tables; for instance, a $^1/_4$ inch plate requires a nozzle diameter of 0.074 inch 20 psi O_2, 8 psi acetylene. Alloys 2S and 3S should be welded with a 5% Si rod. Sheets over $^3/_8$ inch thick should be preheated to 700–800° F. Welds in 2S and 3S are usually thoroughly cold hammered. Illustrations are given for making a variety of welds especially for tubular connections. Hoglund[13] states that the oxyhydrogen torch is still the most widely used tool for welding Al. In his recent review of gas, metal arc and spot welding technique, he gives $^1/_8$–$^1/_4$ inch as the usual electrode diameter using 45–300 amps. depending on thickness of base metal. Alloy 51S (1% Si, 0.6% Mg) is particularly suited for welding, as well as 53 S (0.7 Si, 1.25 Mg, 0.25 Cr). Spot welds in the latter average 350 psi breaking strength.

It is Hermann's experience[2] that the torch should pass 100 liters of acetylene per hr. per mm. thickness, the flame being slightly reducing, not smoky, and the luminous part of the flame being four times longer than the blue cone. For alloys such as Dural the flux should be spread under as well as upon the welded edges. The filler rod should have the same composition as the material to be welded. Before being welded, the edges are cleaned with sandpaper or pumice. No beveling is necessary up to 0.08 inch, between 0.08 and $^1/_2$ inch a 90° V is used; above $^1/_2$ inch, 90° X. After welding, brush, dip in 10% HNO_3, then in hot water.

The most extensive experimental work on aluminum welding appears to have been done by Maier,[3] who showed that, without flux, the drops from an aluminum filler rod leave a pointed end, but with flux the tip is hemispherical. If a non-hygroscopic flux is used the weld is more corrosion resistant than the parent metal. To test whether all flux has been dissolved in washing, daub silver nitrate (1–2% solution) over the joint; if white spots appear repeat the washing in 10% HNO_3. Rolled material need not be preheated. For plate over 0.08 inch thick the oxyacetylene torch is used; for thinner plate use benzol, hydrogen or illuminating gas to get a lower temperature. Forehand welding is best for aluminum and its alloys, but hammering is not generally necessary, except possibly for welds in pure aluminum which must resist corrosion. In the latter case hammering is performed at 300° C. Welds in sheet and plate give 180° bend angles. Silumin welding for electron castings is not good but it is not said what *is* good. In his earlier article Maier gives instructions for making corner welds in aluminum.

Zeerleder[4] gives complete details of gas welding; burner sizes, type of flame, flux composition, size and analysis of welding rod, welding velocity, weld treatment, and charts showing the variation of hardness across the weld in aluminum and two alloys. Tensile tests on gas and hammer welded aluminum sheet untreated and cold hammered are discussed by a German correspondent[5] who states that methane, benzol or illuminating gas may be substituted for hydrogen and acetylene. For plate over $^1/_4$ inch thick a French writer[6] advises two runs in a single V (70–90°) using a torch passing 75–100 liters of acetylene per hr. per mm. thickness of plate, filler rod diameter being equal to plate thickness. The first run is made for a few inches and the second run superposed on it; the seam is finished by cold hammering and annealing. The leftward method is recommended. Oxy-Acetylene Tips[7] recommend pure aluminum and silicon-aluminum rods (no details), and illustrate methods for making various types of joints. The notched butt type is used from 17 to 7 gage; the V notched butt for heavier plate. Except for 51 and 53, welding is not advisable for heat treatable alloys.

Keel[8] points out that thin aluminum sheet is most easily overlap-welded if the sheet is first curved in the direction of the weld. According to Johnson,[9] aircraft manufacturers do not generally weld the heat treatable aluminum alloys. A pure aluminum rod is used for aluminum sheet and a 5% Si rod for castings and Mn-Al alloy. The oxyhydrogen blowpipe may be used as an alternative for acetylene for both aluminum and magnesium depending on personal preference. Fluxes are mixtures of sodium, potassium and lithium chlorides, with or without fluorides of sodium and potassium. The flux used by Surovzev[10] for a special Dural (5 Cu, 0.6 Mg, 1 Mn, 0.7 Si, 0.2 Ti) contained 14 parts KCl, 1.6 NaCl, 30 $LiCl_2$, 7.5 KF, 1 Na_2SO_4; welding was followed by a water quench from 505° C. Bosshard[11] also describes a number of welding pastes. The International Aluminum Association[12] states that the oxyacetylene and oxyhydrogen processes are best, using rods of the same composition as plate or 5% Si rod. Soldering should never be done.

Resistance

The most outstanding work on resistance welds has been done by Hobrock.[15] In his spot welding system, welding is caused by growth of grains across the boundary surface under the influence of resistance heat and critical deformation. A 2-hour etch in 0.5% H Cl solution reveals the extent of the weakest annealed zone around spot welds. Fusion spot welds in an alloy are shown with small cracks due to solidification shrinkage. Apparently in July 1935 there was little reliable information about the design aspects of spot welding aluminum alloys. The microstructure of spot and seam welds in aluminum is described in detail by Haase and Plass[16] who also give a description of spot and seam welding machines. The tensile strength of seam welds is only 50–75% of hard sheet strength but that of spot welds is up to 100%. Bosshard[17] shows that butt resistance welds in Dural ($^1/_2$ inch diam. bars) have excellent physical properties, the hardness of the weld being 93 Brinell, 4 inch away 118. He illustrates his article with six excellent micrographs. Pesljak[18] describes an electric resistance welding machine for aluminum. Zdralek and Wrana[19] give the electrical conditions for welding aluminum wire by means of a non-oscillating condenser discharge. A wire 0.008 inch diam. requires 50 volts with 775 uF capacity and 1.3 ohms resistance in the circuit. Magnesium is spot welded like aluminum, according to Tree.[20] Magnesium alloys require only half as much voltage as the same thickness of steel. Bollenrath and Bungardt[21] give a general review of spot welding Al and its alloys by the recrystallization process, and give mechanical and chemical properties.

Arc

According to Meyer[25] arc welding produces less distortion and does not afford sufficient time for coarse recrystallization, but he presents no convincing facts on the latter point. The arc should be as short as possible and the current as high as possible. He recommends 5% Si electrodes for improved physical properties, and states that preheating helps to prevent porosity. Joint efficiency is 65% in 17 St and 53 SW, and 80% in 3 S-$^1/_2$H and 52 S-$^1/_4$H. Arc welding is impracticable below $^1/_8$ inch. The Lincoln Electric Company[26] has issued tables relating speed, electrode consumption, and size for butt, lap, fillet and corner welds. The 5% Si alloy is recommended as electrode for sheet or cast aluminum. Schimpke-Horn's handbook[27] gives the following values of current: for $^1/_8$-inch electrodes, 60–100 amps.; for $^1/_4$-inch electrodes, 200–250 amps., 18–28 volts, depending on the mass of the parts to be welded. As with other writers, no details of electrode coatings are given. The tendency of the arc to be unstable in aluminum welding is corrected by the Carbo-Flux method;[28] the electrode holder produces a magnetic field around the arc.

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E—Aluminum Welding—Alloys and Castings

Alloys

Applications of welded aluminum alloys to a number of industries are given by Hoglund.[1] He advises 3 S (1.25 Mn) for tank trucks, 51 S for furniture, and 53 S for beer tanks. The two latter are the only heat-treatable alloys that can be welded successfully. Kinzel[11] favors the use of 5% Si rod for Al. The strength and ductility of reinforced joints made with this rod are nearly equivalent to base metal. The attempt to replace Si by Li, Mg, and other elements has been unsuccessful. Jeffries, Nagel and Wood[12] also recommend the 5% Si rod for jig welding and difficult Al welding in general. They also state that welded 53 S is not subject to junction zone corrosion, and that in spot welding Duralumin the line of welding should be cleaned with emery cloth to remove the heavy oxide film. In addition to giving hints on the heat treatment of fusion welds in 18–8 and brass, Eyles[15] recommends that welds in Duralumin should always be heat treated 15–60 min. at about 500° C. and quenched in oil or cold water after welding. The weakened zone in as-welded Duralumin has a tensile strength of only 11,000 psi with negligible ductility.

Leroy[2] states that the difficulties of arc welding heat treatable aluminum alloys for new French Railway coaches were overcome by using a 7% Mg alloy. Boiko and Voshanov[3] discuss the gas and carbon-arc welding of aluminum-magnesium alloys. In gas welding an alloy containing 97.5 Al, 0.9 Si, 1.0 Mg, 0.5 Mn, welds in which have a finer structure than parent metal, Egglesmann[4] finds that good penetration at the root is not easy to attain and that air cooling from 550° C. is advisable to refine the junction zone. Zurbrügg[10] recommends a special hexagonal filler rod for gas welding Avional D sheet (3.8 Cu, 0.55 Mg, 0.5 Mn, 0.08 inch thick). The filler rod contains no Mg but otherwise has the same composition as base metal. Tensile tests show that heat treatment after welding restores tensile strength and elongation to 90% of unwelded values. Mayer-Sidd[5] lists 22 mistakes to be avoided in welding aluminum and its alloys and electron. The specifications for aluminum filler rods of the French welding organizations[6] require a minimum purity of aluminum of 99.5% as analyzed in a fused button 6 mm. thick, 4 mm. diam. deposited on a steel plate.

Torch welding of Mg-Al-Mn alloys, Jeffries, Nagel, and Wood[12] state, becomes more difficult as the Al content is increased. Alloys with 4–5% Al are easily welded; with over 5% Al cracking and hot shortness become serious, and with 8% Al torch welding is inadvisable. Hammering the completed torch weld at 290–370° C. greatly improves the properties. Winston[12] who states that Mg alloys are usually welded by oxyacetylene or electric resistance, recommends special flux and filler rod of the same composition as the part to be welded. The welds should be cleaned in hot water and immersed in a bath containing HNO_3 and sodium bichromate at room temperature for 30 seconds, then painted. The shear strength of single spot welds in $^1/_4$ inch sheet (4% Al, 0.3% Mn, 0.3% Zn, 0.5% Si) is 1900–2200 lbs. per spot. According to Lüder[7] fillet welds in magnesium should be avoided on account of the difficulty in removing flux, and Raymond[8] found that fluxes for electron should not contain chlorides, which are corrosive.

A method of reaction welding aluminum is described by Hermann.[9] The parts to be joined are coated with a paste composed of chlorides of tin, zinc, cadmium and lead, which upon heating produces an alloy of the metals which forms the joint. Heinemann[14] regards hard solders (70–95% Al with Cu, Ni, Ag, Mn, Zn or Sn, according to purpose) as acceptable for joints in Al beer conduits.

Castings

The repair of large aluminum castings by gas welding is discussed by Hermann and Thews.[20] The castings are preheated to 650–725° F. in a special furnace with removable asbestos lids which permit passage of the filler rod. The rod has the same analysis as the casting, and the flux, besides containing the usual chlorides, may also contain borates, phosphates and bromides. The oxyhydrogen torch is best but oxyacetylene or compressed air-illuminating gas may also be used, the flame being

strictly neutral for each process. The softer the flame the better as goggles need not then be used. The puddling operation is described in detail. Heat treatment is unnecessary if preheating is complete and cooling is slow. An anonymous Canadian writer[21] believes that the filler rod for castings should contain a small amount of silicon. The flame should be neutral, not oxidizing, and the torch is held at an angle of 30° to the plane of the weld. Preheating and puddling are necessary. Brett[22] gives a brief review of methods of welding aluminum alloy castings and a French correspondent[23] gives tables of welding times and gas consumptions for repairing aluminum crankcases.

Kennedy[24] recommends rightward welding and preheating for cracks in aluminum and gun metal castings. A German writer[25] gives 105 illustrations of repairing aluminum crankcases by welding. To repair Al die castings, according to Trunschitz,[26] the flame should be neutral, the tip one size smaller than for similar work on steel, and flux and special alloy filler rod (composition not stated) should be used. Dornauf[27] believes that gas welded silumin castings should always be re-heat treated. Berzin[28] deals with the repair of Electron castings, by welding, Thews[29] with the repair of Al castings and Reininger[30] reviews methods for welding and soldering Al castings.

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APPENDIX VI

Recent Literature on Welding Cast Iron

A number of articles deal with the hard, unmachinable zone sometimes found in cast-iron welds. Baillon[1] illustrates the condition by means of photomicrographs. A correspondent to a German publication[2] recommends that at least 2% Si must remain in the weld to prevent hard spot and that the welding rod must therefore contain about 10% Si, the excess being fluxed. Tibbenham,[3] however, believes that welding rods for cast iron need contain only 2.4 to 3% Si. The range of compositions for cast-iron filler rods given by Reininger[21] is: 3.05–3.3% C; 2.09–3.36% Si; 0.34–0.56% Mn; 0.20–0.60% P; 0.070–0.076% S. Si in filler rod minus Si in part to be welded = 0.7%. To avoid hard spots in gas welding Sixt[4] relies on a special alloy rod (Metta, composition not given), whereas Müller[5] and Durglund[24] recommend welding with Monel metal rods, the former stating that nitrides are also avoided in this way. Rollason[6] discusses the effect of type of structure on the method of welding from two standpoints; 1. Composition; for welds that are not to be machined the mild steel electrode is satisfactory; otherwise a high silicon rod with a fluxing agent is required. 2. Rate of cooling; rapid cooling is always desirable to refine the graphite structure and maintain a pearlitic matrix, but its advantages must be balanced against the likelihood of hard spots. Stress annealing at 500° C. and normalizing at 800° C. are beneficial. Obrebski[19] also discusses hard spots as related to structure.

Rollason also enumerates the difficulties in welding malleabilized cast iron. Tileman[7] recommends an electrode containing 0.2 C, 0.06 Si, 1.1 Mn, 0.02 P, 0.03 S, with a coating consisting of 40–50% graphite, 1–5% Fe_2O_3 20–25% SiO_2, 10–20% CaO, with small additions of MnO, Al_2O_3, MgO and alkalies. Afanas'ev and Sorokiskii[8] state that the hard zone is impossible to avoid in welding malleable cast iron but that this zone is not ordinarily dangerous, plastic changes under stress occurring outside the weld. High internal stress due to overheating and the presence of bubbles due to the combustion of carbon must be taken into account.

Methods and examples of repairing cast-iron parts by welding are given by a number of writers. Buschmann[9] deals with repair jobs on thin castings, Kohrs[10] with repairs to locomotive frames and cylinders, and Titscher[11] with hot welding cast iron frames using an electrode depositing iron containing 0.25 Ni, 0.75 Cr. A welding jig for cast-iron repairs is described by an English correspondent.[12] Davis[13] gives details of the metallic-arc and carbon-arc processes for welding cast iron and discusses shrinkage cracks and non-ferrous electrodes. Arc and gas hot welds in cast iron are equivalent in strength, according to Baatz.[22] Bronze welding is done on relatively thin work. The Gussolite cold method requires special filler rod and experienced welders, and ordinary cold arc welding almost always requires studding or other strengthening devices. In the opinion of Pearce,[14] the carbon content is the main factor in welding cast iron, the silicon question being really a question of the structure of the carbon. The French Institute for Gas Welding has issued specifications relating to weld metal for cast iron.[15] Brown[20] states that sheet steel may be instantaneously welded to cast iron without seriously disturbing the structure of the cast iron. Heavy sections of steel may be welded to cast iron by welding to the projecting ends of large steel bolts treated into the cast iron.

The general technical problems of welding cast iron are discussed by Stieler,[16] who depends to a great extent on microstructural investigation. Molds for the hot welding of cast iron must be made of graphite plates; for gas-welding the mold may be made of sand painted with graphite. A current strength of 400–600 amps., 50–60-volts is recommended. After a pool of metal has been formed, a graphite electrode can be used, or cupula iron can be poured in. Ventilation for the welder is important. Castings that have been subjected to conditions of growth should not be welded. For thin sections gas is better than arc, gray cast-iron welding rods being used for both processes. For cold welding, gray cast-iron rods should not be used, nor are mild steel

electrodes acceptable on account of porosity, weakness and hard spots. Non-ferrous electrodes are called for in cold welding. For cutting cast iron, a multiple-burner torch is used, the oxygen stream having the purely physical function of blowing a smooth cut. New cutting torches with multiple burners, such as the Pyrocopt[17] are now available. Flame cutting using low-carbon steel plates, Moss[23] states, is adopted for low-quality cast iron or where high speed is required. The ordinary cutting method is mainly used for veeing and demolition. The new edition of the text-book on Arc Welding by Schimpke and Horn[18] contains a detailed description of the cold and hot processes. For hot welding only cast-iron rods are recommended.

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APPENDIX VII

Recent Literature on Resistance Welding Electrodes (1935 to May 1936)

The most informative article on electrodes in the past year has been prepared by Larsen,[1] who has determined the increase in tip area as a function of number of spots and tip pressure when spot welding cold-rolled steel and 18–8 using copper, Elkoloy, and Mallory metal electrodes. He concludes that the ability of an electrode to retain hardness at elevated temperature is the chief criterion of usefulness, apart from conductivity. Hunt and Davidson[2] state that one electrode is usually $^3/_{16}$–$^1/_4$ inch diameter, the other being larger in diameter and having a convex face, 20° angle. Rollers for seam welding are made of copper and are trued by work hardening. Projection welding dies are water cooled and are faced with Elkonite. In order to obtain uniform stress distribution in spot welding aluminum, Hobrock[3] believes that the angle between the conical part of the tip and the aluminum sheet should be 8.5–11.5°. Komovski[4] prevents deformation of the tips of copper electrodes by surrounding them with conical shells of heat-resisting steel (composition not stated). White[5] states that copper tips are best for high-resistance materials such as iron, nickel, nickel brass, but that copper-rich copper-tungsten alloy is advisable if long life is required. Tungsten tips are best for low-resistance materials, such as copper or aluminum.

The electrical conductivity of electrode tips for spot welding cold-rolled steel should be at least 75% of the conductivity of pure copper, according to Weiger[6] and the hardness at room temperature should be 65–85 Rockwell B. Experiments showed that a water-cooled tip made with $^1/_4$ inch of solid metal from face of tip to water was the most economical. Copper-tungsten alloy is used for projection welding dies. Fassbinder[7] lists the causes of deterioration of spot welding electrodes as electrical, thermal and mechanical. In the final compression dwell during spot welding the pressure is 5700–7100 psi, and the temperature is about 100° C. below the melting point of the electrode. Electrodes are usually made of copper, the tip being conical, sometimes spherical. The bottom of the water cooling recess in the screwed-on tip should be well below the threads, and the thickness of metal between the face of the tip and the water should never be more than $^3/_4$ inch. Sintered 50–80% W-Cu alloy is used for stainless steel. Alloys of copper with cadmium, beryllium or cobalt, and ternary mixtures of them are also used. Cuivrelect (a secret composition) is also good but copper-silver alloys are not suitable. Cogan[15] states that tungsten-copper is best for facing flash and projection welding electrodes; it should be water cooled and preferably silver soldered to the backing. Hook[16] mentions beryllium-copper and chromium-copper as suitable for spot welding electrodes. According to Stott,[17] copper containing 0.45 Be and 2.6 Co is used for spot welding stainless steel and for some seam, flash and projection electrode parts. Benford[18] also mentions this alloy. Hansen,[19] a recent German writer, refers to copper rollers only for seam welding. A proposed Welding Handbook article[20] gives much the same recommendations as Cogan[15] but alludes also to "alloy" copper.

A portable automotive spot welder[8] is mentioned as being equipped with electrodes having 90% electric conductivity and 120 Brinell, and another anonymous writer[9] uses a hard copper-base alloy for spot-welding aluminum. Zimmerman,[10] reporting an investigation by Jones, states that water cooling can be overdone. If too much of the tip is hollowed out there is a loss of metal cross section and an accompanying rise in current density. A copper electrode, according to Languepin[11] can support 5700–11,400 psi at average rates of welding, but at very rapid rates (97,000–130,000 amps. per sq. in. for mild steel) the electrode will support 14,200–17,000 psi. Rogers, discussing a paper by Jeffs,[12] states that tips for spot welding non-ferrous metals should be kept the full width of the electrode, than radiused off by trial and error until the best results are obtained. Copper-tungsten and copper-cadmium tips are used: the copper-tungsten alloy is buried in the electrode. Cooling should be so efficient that immediately after a weld is made, the tip may be touched without one's finger being burnt. De Longcamp[13] recommends small contact tips made of special alloy, large tips being condemned. Schimpke and Horn[18] give the dimensions of spot welding tips for different thicknesses of mild steel, and believe that dome-shaped tips are best for galvanized or plated metal. Like many other writers, they neglect to state the composition of the electrodes. The following table prepared by Keeslyakov[14] indicates the properties of some electrode materials.

Material	Electric Conductivity Copper = 100	Specific Gravity	Hardness Brinell	Hardness Rockwell B	Hardness Rockwell C	Tensile Strength, psi	Electric Resistivity ohm per mm²
Elkonite: manufacturer's data	25%	.....	225	97	...	220,000	.....
Elkonite: data obtained by the Electroworks	21–44	13.2–14.6	...	80–100	46–62	210,000	0.048–0.055
Elmet: data by Electroworks	27–31	13.6–14	...	63–70 and 90–97	...	.....	.....
Soft Copper	100	8.8–8.9	30	.....	...	.....	.....
Hard Copper	100	8.8–8.9	80	0.40	...	60,000	0.017–0.018

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APPENDIX VIII

Recent Literature on Metal Transfer in Welding and Allied Topics

A—Metal Transfer in the Arc

The two problems of metal transfer in the arc appear at present to be the mechanism of deposition and the rate of deposition. A good fundamental statement of the major factors in arc deposition has been given by Boyd[1] Conrady[2] applies the method of resultants to explain deposition. High speed photographs of overhead welding showed no drop transition with low-carbon bare electrode positive; this is explained by the fact that the ion stream from the cathode overcomes gravitation, but not from the anode. With a coated electrode there is a resultant upward on account of the small restricted anode spot and the action of the active, excited coating. Schimpke and Horn[3] state that the effect of the coating in overhead welding is to avoid dripping. But Brück[4] recommends dipped electrodes D.C. for overhead and vertical welding; coated electrodes should not be used. Erber[5] points out that vertical welds should not be made in a downward direction because molten metal is likely to drip down and freeze on cold parent metal, giving no penetration. It is expected that the analysis of the high speed motion pictures of metallic arcs made by the General Electric Company, soon to be published, will delimit some of the most baffling problems. Philips[6] have recently made radiographic films at 50 photos per second using an X-ray ciné camera. The X-rays distinguish between core and coating, and penetrate the dense clouds of vapor around the arc.

The effect of coatings on arc characteristics has been studied by Tichodeev,[7] who found that non-stabilizers, such as Al_2O_3, Fe-Si and $FeSO_4$ from pickling (the electrodes containing 0.07 C, 0.04 Mn), raised the arc voltage, whereas stabilizers such as Fe_2O_3 and calcium compounds lower the voltage. Non-stabilizers eliminate the pinch effect and the drop is deposited then solely by gravity. Unusually long arcs ($1^3/_8$ inches) are described by Matting and Lessel[27] using a copper electrode (0.16 inch diam.) with refractory coating at 100 volts, 120–220 amps. In Akazaki's method[30] of arc welding, an asbestos covered electrode is laid in the welding groove. The operator then strikes an arc between base metal and the end of the electrode by means of an auxiliary wire. The electrode deposits itself. The method bears a striking resemblance to the Strohmenger-Slaughter method used about 1914. Waclawik[8] shows the effect of compensation current on the stability of the D.C. metal arc. Increasing cold work, according to Kessner and Specht,[9] increases the spatter of bare electrodes on account of the accompanying decrease in thermal and electrical conductivity which caused slower melting. See Swinden Appendix IV (c). For subaqueous welding Hrenoff and Livshitz[10] showed that D.C. is better than A.C. and that the electrodes should be coated. The relative rate of melting of the electrode is slower under water than in air, but the melting of the plate metal is faster.

There is still division of opinion concerning rates of deposition in the arc. The majority view is expressed by Shepherd and Carpenter[11] who show that the number of globules per second is five times greater with bare than with coated; the longer the arc the greater the nitrogen pick-up. Miller[12] also found that the globule is much smaller (no details) with bare than with coated electrodes; the maximum oxidation would occur if the metal was transferred as a mist. With good covered electrodes polarity and type of current have no effect on rate of deposition. Extensive tables by Thomasson[13] show that the weight of metal deposited per rod for a given current and diameter is 25% greater for coated than for bare electrodes. As current is increased, arcing time is decreased for both coated and bare electrodes. Strelow[14] also found that coated electrodes give smaller globules and more per second than bare. He believes that iron oxide is a necessity for the production of an arc or spark between steel electrodes; heating the ends to a red heat simply produces the oxide but is not otherwise essential.

Heimke rejects Rossell's statement[15] that the globules are larger with coated electrodes than with bare, and believes that confusion exists between globules and bubbles in the arc. Ronay's view[16] is that coatings and shielded arc cut down the transfer period by steadying the arc, thus insuring high power input. Some of the metallic oxide coatings change the volume of the drop by altering surface tension, but the effect of the carbon content of the electrode, increasing which from 0.03 to 0.17% increased the globules per minute by 30% regardless of surface finish of electrode—this effect is ascribed to the increase in electric resistance by carbon

giving a 22% slower melting rate for 0.06% C electrodes as compared with electrodes containing 0.16% C. The smaller globules from the higher-carbon electrodes are less exposed to the atmosphere and give an improved penetration ratio; defined as the ratio of volume of globule to volume of base metal melted during the formation and transfer of the globule. Ronay points out that his results scarcely account for the general preference for dead mild electrodes (less than 0.14% C) but does not discuss other aspects in which he disagrees with other investigators. In particular, Tichodeev[17] showed that globule size up to 0.25% C is independent of the carbon content in carbon arc, atomic hydrogen and oxyacetylene welding. Tichodeev also found that the surface tension of iron calculated from globule shape was in good agreement with the value obtained by other methods.

Rate of deposition, according to Waclawik[18] depends on cathode drop and current (resistance heating) but not on length of arc. Therefore, the formation of globules, causing variations in arc length, has no effect on rate of deposition unless variations in generated current are induced. The long arc with its higher voltage requires more power than, but has the same rate of deposition as, the short arc, which is more quiet. Legrand[19] found that the time for fusion is less with A.C. than with D.C. for all sizes of electrodes up to 5 mm. The A.C. arc has a lower resistance than the D.C. because the passage of ions and presence of the magnetic field (constant in direction) in the D.C. arc tend to throw the conducting metallic ions outside the circuit of the arc. A good general review of arc phenomena is given by Osborne[20] who states that fusion depends on current, conduction on voltage. His oscillographs show the ignition voltage peak on both positive and negative halves of the A.C. welding cycle. Siemers[28] gives a general review of the principles of arc and resistance welding and Driessen[29] gives an elementary explanation of the Siemens oscillograph in welding.

Arc temperature, according to Osborne, is approximately the boiling point of the electrode, but is also affected by other factors, such as current surges. The temperature of the copper arc, 4 to 26 amps., determined by the sound velocity method of Suits[21] is 4200° ± 200° K. for short arcs (3 cm.) and 4000° ± 200° K. for long arcs (13 cm.). Allen and Hesthal[22] give the temperature of the chromium arc as 4060° K. The temperature of the carbon arc, Gray[23] found, is 5300° ± 300° K. over a range of 7 to 21 amps. D.C. with standard projector carbon. But Righini[24] found 3800 to 4800° K. with arc lengths up to 10 mm. and 5 amps. D.C., calculated from CN band intensities. Kirschstein and Koppelmann[25] describe high-current arcs up to 200,000 amps./cm.^{2} with temperatures between 13,000 and 17,000° K. Notvest[26] states that the temperature of the carbon arc is 4500 to 5000° C. depending on spacing and graphite content of electrodes.

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B—Magnetic Blow and Generator Characteristics

A good elementary discussion of magnetic effects such as blow in the welding arc is given by Meller[1] whose work is largely reproduced by Notvest.[2] The discussion is illustrated by simple diagrams and photographs of blowing arcs with various arrangements of lead-ins, and concludes by showing that a blow magnet, horseshoe type, with the electrode between the prongs will eliminate undesirable blow in automatic welding. Schellong[3] develops the practical aspects of Meller's discussion, suggesting that the electrode be bent 180° for welding inside profiles, and that the lead-in should be capable of being attached wherever desired; for example, against the web in welding stiffeners on beams. Winterfeld[4] outlines the path best traveled by the electrodes to avoid blow in welding Z sections and plate girders. According to Sticpewich,[5] the electrode should be equidistant from front and sides of crater for best penetration, especially in automatic welding. With coated electrodes the seam should be arranged to prevent liquid metal draining away. Since A.C. gives less blow than D.C., Arcos[6] has found that thicker electrodes and higher currents can be used with A.C. than with D.C. Mehls[7] gives a brief discussion of the following factors affecting magnetic blow: 1. Preparation of material to be welded. 2. Length of arc, which should be as short as possible. 3. Suitable inclination of electrode. 4. Lead-in, which in many cases should be near the electrode. 5. The arrangement of additional parts to give better mass distribution, especially in profiles. 6. Current density, on which opinion is divided. If the electrode is sloped toward the deposit a porous deposit is obtained; in the same way arc blow may cause porosity, according to a Polish correspondent[8]. Using patterns obtained with iron filings, Du Rietz[26] illustrates the factors affecting magnetic blow of inclined and vertical electrodes, D.C. and A.C. The effect of heating the electrode above Ac_2 and of two electrodes in juxtaposition is also discussed.

The volt-amp. characteristics of welding arcs are discussed by Léonard,[9] particularly with reference to arc length and frequency. Shibata[10] shows the effect of about 30 ordinary compounds on arc voltage and melting time. Okada[11] also studied arc voltage as a function of coating material. Silica, clay, borax and Na_2CO_3 raised the voltage but $CaCO_3$ and iron oxide lowered it. Feszcenko-Czopiwski[12] showed that spatter loss was 11 to 12% for abnormal steels (0.12, 0.60 and 0.85% C), but only 5% for normal steels. Amp-volt relationships for the carbon arc (electrodes 12 and 18 mm. diam.) as affected by longitudinal and transverse magnetic fields and by the structure of the deposited metal (0.1 to 0.8% C) are given by Hrenow.[13] Equipment for carbon-arc welding and the effect of arc length and protective atmosphere on the quality of the weld are discussed by Hansen.[14]

General reviews of the characteristics of welding generators are given by d'Aboville[15] and Fink.[24]

Waclawik[16] states the advantages and disadvantages of the cross-field generator and in another article[17] discusses the question of A.C. *vs.* D.C. According to Ferney,[27] the most important characteristic of welding generators is electrical inertia as measured by "fictitious" resistance, which is the ratio of open-circuit voltage to peak short-circuit amperage. Volt-ampere curves of generators are analyzed on this basis and methods of introducing damping windings are explained.

Long[18] has prepared a good article on A.C. equipment theory in which he states that the short arc, as in A.C., is essential for good penetration. Steinert and Reddie[19] also discuss A.C. arc welding apparatus, and Blankenbuehler[20] gives a complete description of a new generator with high electrode-deposit efficiencies. Candy[21] gives details about transformer and circuit characteristics and their effects on arc maintenance. Illustrating his discussion with useful charts and tables, Willey[22] compares the static and dynamic characteristics of single- and multi-operator D.C. generators, giving detailed information on costs. He also describes the characteristics of a high-frequency (150 cycle, single-phase) single-operator generator, 80 volts A.C., 10–100 amps. The AEG[23] have described the operating characteristics of their 30 and 46 kva. welding transformers, and Matting[25] gives the generator characteristics of hand and automatic arc welders.

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C—Physics of the Arc

Probably the most outstanding of recent discoveries in arc welding was made by Doan and Schulte.[1] They found that with clean "pure" iron electrodes in 99.5% argon, no arc is formed unless the short circuit current is greater than 110 amps. and A.C. voltage > 62 volt. There is no crater and, therefore, no penetration, globules growing to about $^1/_4$ inch diam. before being detached solely by gravity. The rate of deposition per kw. hr. is approximately the same in argon as in air. Suits[2] explains the absence of crater formation in pure argon as due to the impossibility of dissociating monatomic gases such as argon, the dissociated gas combining at the catalytic parent metal surface with evolution of welding heat. He found that the gas temperature in a welding arc between an iron plate and a commercial rod 5 mm. diam., 125 amps. D.C. in air was 6000° K. and that 81% of the oxygen and nitrogen existed as atoms. Mason[3] states that the pronounced wandering of the arc in pure rare gases is caused by oxides in the electrodes.

As a result of arc welding experiments in nitrogen atmosphere, Schamowski & Prochorow[22] found that nitrogen pick-up is smaller, the purer the nitrogen from oxygen. Voltage-arc length curves determined by Stübing[4] for arcs between tungsten electrodes in helium showed that the length at which the anode drop vanishes is almost ten times greater than in nitrogen. In this connection Nottingham[5] states that data on arc characteristics which depend on the spacing between electrodes have no significance, unless the arc proceeds in a straight line from one electrode to the other; and this is very seldom the case on account of wondering at anode and cathode. Two copper electrodes in contact were drawn apart by Betz and Karrer[30] while current up to 100 amps. was flowing. A voltage of 12.2 volts (the cathode drop of the copper arc) was always produced in 10^{-5} seconds as measured by oscillograph.

If the definition of an arc given by Ornstein and Brinkman[6] is accepted, discharges in noble gases are not arcs because the discharge mechanism is not thermal in nature, these gases having small capacity for collisions of the second kind. They define an arc as a discharge in a gas with Maxwell distribution of particle velocities in which excitation, ionization and neutralization are produced by collision of molecules. In a recent paper[7] they develop a relation between the thermal conductivity and specific heat of the gas in the arc and its temperature, which can be calculated from spectral intensities. Poritsky and Suits[8] show that arc temperature may also be calculated from sound velocity measurements. A phototube for studying cathode temperatures in hot cathode arc discharges is described by Koller.[24]

Plesse[9] found that the tendency for arc formation was less in hydrogen than in nitrogen and studied the characteristics of the transition from glow to arc of nickel electrodes in argon. An enormous amount of data on the mechanism of arc discharge is given by Becken and Seeliger[10] who determined the relationship between arc current and voltage and pressure for arcs between plane parallel water cooled electrodes of Cu, Fe and W (the anode being Cu in each case) in nitrogen and neon. A new type of tungsten arc was discovered which seemed to be a mixture of thermal (ordinary arc) and auto-electric emissions, although no inhomogeneities were observed in photographs (1/1000 sec. exposures).

The theory of the arc on the basis of energy and electron balances has been attacked anew by Holm, Kirschstein and Koppelmann.[11] The two latter[12] traced the cause of the variations in the diameter of free-burning arcs (copper or tungsten electrodes, D.C. and A.C. up to 1200 amps.) to metallic vapors from the electrodes which are whirled by magnetic and thermal forces. Light intensity is less from the arc in hydrogen than in air. The forces at the cathode of a copper arc in hydrogen and nitrogen at various pressures have been measured by Robertson,[29] who made the cathode a pendulum.

Hörmann[13] shows that ionization in the carbon arc is not appreciably affected by impurities, and develops a method for calculating the temperature distribution perpendicular to the axis for any arc. He has also determined the longitudinal field strength in freely burning and stabilized arcs at atmospheric pressure. Kotecky,[14] however, found as a result of measurements of the arc characteristics of all combinations of C, Cu, Fe and Al, 10 mm. horizontal electrodes, 1 to 5 mm. spacing,

1 to 20 amp. that arc temperature as a function of current varied with the chemical purity of the electrode. Pierucci and Barbanti-Silva[15] observed exceptionally strong self-inversion of the Na-D line in the glass arc formed by covering a carbon electrode with glass during the arcing process.

Newman's investigation[23] of cold cathode arcs between carbon electrodes in air at pressures of 0.01–1 mm. mercury using roughened surfaces showed that thermionic emission cannot be solely responsible for starting and maintaining the arc. Lamar[28] found that the energy loss in the positive column of an arc in nitrogen at atmospheric pressure can be explained to within a few per cent by heat conduction and radial diffusion of atoms. The effect of impurities having lower ionization potentials than nitrogen was also investigated.

The relationship between length, current and voltage of the D.C. welding arc in air and the lowest arcing potentials (11.7 volts for bare iron electrode, 4 mm. diam.; 12.7 for dipped welding rod; 5 to 20 amps.) was determined by Engel[16] using the oscillographic method. The fluctuations of voltage of a high amp. welding arc were traced to the variable cooling of the arc gases and changes of heat conductivity of the electrodes by globule transition. The cathode drop calculated from the energy balance obtained from the heat of fusion of the electrode materials was in agreement with the lowest arcing potentials. The energy balance in a copper arc can only be obtained, according to Engel, by taking into account the lowering of the thermal conductivity of the electrodes through oxidation of the copper by the air. By polishing the anode surface, Suits[17] found that the irregular variations of arc voltage and brightness with copper electrodes in air was reduced to a very small amount at atmospheric pressure. Druyvestyn[26] states that a thin oxide layer on the cathode is an additional source of electrons in the arc. The minimum voltage necessary to strike an arc in air and hydrogen is given by Gaulrapp[27] for a large number of metals, and the current densities at the cathode for zinc and carbon arcs is given as a function of pressure. He also determined the volt-ampere characteristics of zinc arcs in air and hydrogen by means of an oscillograph.

Interesting photographs of arcs (copper plated carbon electrodes) stabilized by nozzles in hydrogen and water vapor are given by Lotz.[18] He states that the arc in oil or water burns in practically pure hydrogen, and finds that the voltage gradient in H_2O is fundamentally different in free-burning than in stabilized arcs. Cobine[19] has recently prepared a lengthy discussion with bibliography on the subject of low-pressure arcs, and finds that there is a linear relation between reignition potential (1 mm. gap; carbon electrodes, 6.4 mm. diam.; A.C.) and gas pressure (N_2, CO_2, O_2 and air) by means of the oscillographic method. Hutchisson, Osgood and Fearon[20] have measured the electrical conductance of short air gaps up to 10,000° A, 0.0001 to 1.0 volt (to avoid ionization). When metallic contact has been lost charged particles carry the current, and the volt-amp. relation is quadratic. Instantaneous arc discharges (3000 amps.) as produced by Wallraff,[25] commence as glow discharges, then, after 10^{-6} sec. or so, they change to arc. The voltage (35–40) was practically independent of current. Several papers on arc phenomena were presented at a recent Japanese Congress.[21]

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D—Gas

There has been practically nothing published during the last two years on metal transfer in oxyacetylene welding. Tichodeev[1] found that the rate of globule formation was 10 to 12 globules per minute in the neutral flame, and that the globules were 30 to 40% smaller in an oxidizing flame. The rate for atomic hydrogen welding was 12 to 15 globules per minute. Bainbridge[2] states that the rate of deposition is proportional to the square of the welding rod diameter and is 1 lb. per 14 or 15 cubic feet of C_2H_2 (rod size not stated). A thin rod gives a heavy top bead but thick rods cool the molten metal, giving small top and under beads. The present position of the metallurgical effects of the oxyacetylene flame is dealt with among others by Critchett[3] and Streb and Kemper[4], the latter of whom state that splashing is due to evolution of water vapor in the melt through reduction of iron oxide by hydrogen.

The temperature and pressure characteristics of burners appear to have attracted more attention that the problems of metal transfer. Streb and Kemper[5] have measured flame temperatures for O_2/C_2H_2 ratios from 0.54 to 5.5 by volume. Between 1.2 and 1.5 a maximum temperature of 3400° C. is attained. They also studied the pressure variations connected with the expansion of the nozzles during welding, and in another article,[6] showed that it was not economical to dilute acetylene with illuminating gas. Sauerbrei[7] has determined the limits within which variations of acetylene pressure must be kept to attain economical results. A comprehensive review of reactions in the oxyacetylene flame is given by Kemper[8] who includes diagrams showing temperature and gas composition at various points in the flame. Séférian's monograph[9] on welding flames includes the theory of combustion and spectrum studies of the oxyacetylene, atomic-hydrogen and other welding flames. The maximum temperature in the O_2/C_2H_2 flame is given as 3100° C.; in the atomic hydrogen flame: 3400° C. In an earlier article[10] he showed that the theoretical temperature of the atomic hydrogen flame was 4030° C., but that heat absorption due to formation of atomic hydrogen cut this down to 2950° C. In good agreement with Streb and Kemper[5] he states that maximum flame temperature is attained with a ratio: O_2/C_2H_2 of 1.5. A method for calculating welding flame temperatures considering composition and

dissociation of all constituents is given by Michaud.[11]

Concerning the physics of the oxyacetylene flame, Coward[12] reports values for the ignition temperature of C_2H_2 in air and oxygen for various time lags and pressures. Time lag has practically no effect in air, the ignition temperature rising from 430° C. at 760 mm. to 550° C. at 50 mm. Pignot[13] reviews existing values of the ignition temperature of hydrogen, oxygen and other gases as a function of pressure in air. Schuster[14] gives the average specific heats and total heat contents of C_2H_2 and hydrogen from 0 to 1700° C. in tabular form with 100° intervals. Defining the power of a flame as the quantity: $^1/_2$ ignition velocity multiplied by heat of combustion per unit volume, Brückner, Becher and Mathey[20] found that the acetylene flame is 3 times more powerful than the hydrogen flame; the difference was still greater for illuminating gases, methane and carbon monoxide. The total energy of formation of C_2H_2 is calculated by Serber[15] as 14.9 volts, the experimental value being 15.2. Malinowski and coworkers[16] showed that an explosion wave in a mixture containing as much as 22% C_2H_2 was extinguished by a counter wave generated by an electric spark, transmitted through an air gap.

Excellent accounts of experimental investigations of oxyacetylene welding are given by Bainbridge[21] and Gothron.[22] The former deals particularly with new techniques. Gothron compares right-hand with left-hand welding with respect to gas consumption and physical properties. There was 25% saving in time and materials, 40% better bend angle and 22% better tensile strength with right than with left, using 0.16–0.59 inch steel plate. If 0.32 inch plate is welded without veeing using 0.12 inch spacing, there is little saving in time and gas, but a considerable saving in filler rod. Using the two-torch vertical welding process, no veeing is used for plate less than $^1/_2$ inch thick; above $^1/_2$ inch the edges are double veed. The two-torch process is most advantageous for thick plate. Gothron found that T joints welded from the back were better than fillet welded T joints from the standpoint of economy in time and materials. The so-called "cold" welding process for steel, described by Lewis[23] requires a torch with patented tip having two preheating flames situated half-way up the nozzle. An excess acetylene flame is used which carburizes the steel and permits welding at relatively low temperatures.

An elementary explanation of the automatic atomic hydrogen process is given by Déglon[17] who states that for low carbon steels the clamps must not be too close together otherwise hydrogen blow-holes will be formed. In high carbon steels this is not so important because the hydrogen is attacked by the carbon. Sarafonov[18] also discusses the atomic hydrogen process, giving the optimum distance between electrodes and the relation between hydrogen consumption and arc intensity. Using a spectrum—photometric method, von Wartenburg and Wehner[19] found that the temperature attained in the iron-thermit reaction is 2400 ± 50° C.

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APPENDIX IX

Recent Literature on X-ray Weld Testing

The growing importance of the X-ray inspection of welds was emphasized at the A. S. T. M. Symposium on Radiography, June 30, 1936. At this Symposium, Hodge pointed out that there are at least 40 X-ray equipments in this country in regular use for welded joints from $^1/_4$ to $4^7/_8$ inches thick. The equipments are mainly 200 kv. or 300 kv. at 10 MA although recently some 400 kv., 5 MA tubes have been placed in service. Lester, who spoke on X-rays in welding specifications, is engaged in standardizing X-ray methods for welded joints. Defects in welds in pressure vessels and steel pipe as revealed by X-ray are, in order of prevalence, according to Van Horn:[27] 1. slag inclusions; 2. porosity; 3. cracks; 4. incomplete fusion between weld and base metal or between two layers of weld metal.

A brief discussion of X-ray equipment and interpretation of results is given by Isenburger,[1] who states the advantages and disadvantages of rotary switch as compared with vacuum tube rectification, and who has had little trouble with air-cooled X-ray tubes. Isenburger[24] also describes a good method for calculating the location of a defect inside a weld, using X-ray photographs. He supplies details of portable X-ray equipment and convenient exposure charts. Although outfits operating between 250 and 550 kv. have few possibilities, the use of over 600 kv. is promising. He believes that expert interpretation of X-ray films of welds is necessary, especially in the field. Schmidt,[25] who states that a weld in steel $5^1/_2$ inches thick can be radiographed in less than one minute with a 400 kv. outfit, does not appear to share the above view concerning excessive scattering at high potentials.

The method of operation of a 250-kv. outfit for welds is described by Mochel and Bates;[2] a few details of cassettes and a focal adjustment indicator are given. Trepanned specimens are also X-rayed. Wever[3] recommends X-rays as the best method for judging the quality of welds. The routine X-ray examination of steel castings and welds at the Naval Gun Factory is described by Underwood and Ash.[4] Several articles[5] have appeared dealing with the portable equipment of the German Railways and the applications of X-rays to welded pipes and pressure vessels. For welds in mild steel, Widemann[6] recommends 100–120 kv., 4–5 MA, a tube distance of 20 to 40 inches and a 2-minute exposure. He[21] gives the minimum size of detectable defects in the Gamma-ray testing of welds.

Widemann[23] also describes an ultra-short wave-length X-ray outfit (about 0.1 Å). For $1^5/_8$-inch boiler plate welds the tube distance is 4 inches and a sheet of tin 0.04 inch thick is used to shield the film from scattered radiation. To identify X-ray films, particularly of welds, Hövel[22] suggests that the identification numbers be stamped in a layer of plastic cement applied to base metal near the weld, which does not involve the time-consuming filing necessary for soldering lead tags or the injury to fatigue strength caused by stamps. The

cement contains a high-lead filler. One of the main advantages of X-rays, according to Bleichert,[7] is that they give a permanent record. Gamma rays, he states, are useful for welds up to 2 1/2 inches thick and are better for fillet welds than X-rays. For welds in 1/2-inch steel Adrian[8] uses 150 kv., 7 MA, a 10-second exposure and a grid.

Berthold[9] in his numerous articles on radiographing welds, has dealt with almost every phase of the subject. In 9(*a*) he gives complete details concerning the standard German methods for X-raying welds (DIN 1914, August 1935) with a chart showing the magnitude of the smallest defect that can be detected as a function of tube voltage and weld thickness. A crack perpendicular to the X-ray beam must be at least 0.1 mm. thick to be detected in a 10-mm. plate. The ratio of distances: cathode to weld/weld to film must never be less than 6:1. The size of a defect is estimated by seven wires of graded diameters radiographed with the weld for iron, Al and Cu. Film dimensions, intensifying screens, and the fluorescent screen method are also discussed. Eighteen radiographs illustrate the interpretation of defects in V, X, I and U welds, fillet welds, T and lap joints.

For Gamma-ray radiographs Berthold and Stäblein[9*f*] demonstrated a sensitivity of 3% under the following conditions: 300 mg. mesothorium, 4 inch weld thickness, thorium-film distance 29 inches, weld distance 1/4 inch, 13 hrs. exposure, using Agfa X-ray safety film, super special blue with Degea intensifying screen. Methods are described for using Gamma rays in the inspection of welded reaction chambers. In 9(*g*) Berthold used the back-reflection method to calculate elastic shrinkage stresses in welds. Stresses up to 40,000 psi were detected in arc-welded mild steel butt welds. In common with other investigators Berthold believes that the one big disadvantage of radiography in welding is the absence of close correlation between mechanical properties and the numerous types of defects revealed and not revealed by X-rays.

Pullin[10] has also developed the X-ray testing of welds from several viewpoints. In the article in *Engineer* he analyzes 25 radiographs in welds and describes a simple penetrameter and visual apparatus for testing air-craft joints. Radiographs agree with tensile tests in general but not on a percentage basis; that is, a 10% increase in intensity of defects may not be accompanied by a 10% decrease in tensile properties. In the Committee Report, Pullin states that the small cavities often detected in welds are of small importance for all mechanical properties except fatigue strength in which case the fine inter-crystalline cracks associated with the cavities are damaging. At the present time, the interpretation of radiographs of welds is still difficult. Spectrum analysis, using the Laue method or back reflection from the bottom of a squared and etched hole, is a certain method for indicating unrecrystallized areas of plastic distortion. But the degree of resolution of the Kα doublet of cobalt must be very good to permit measurement of the small parameter changes associated with residual shrinkage stress even with an accuracy of resolution of 1 in 20,000. In the presence of plastic distortion it would seem out of the question to detect residual stresses by X-ray spectrum methods.

The correlation between X-ray examination and mechanical properties has been investigated by several investigators without practical results. Wallmann,[11] whose radiographs are remarkably clear, showed that for carbon-arc welds there was reasonable agreement between the number and distribution of defects and the static and pulsating tension tests but no agreement with bend and impact tests. Söhnchen[12] also found little relation between radiographs of welds in 1/2-inch plate and impact tests. His explanation is that machining removes some of the defects and poor penetration is not revealed by the X-ray. Bierett[13] showed that the correspondence between radiographs and fatigue results on welded beams was not particularly good. According to Tofaute,[14] bonding defects decrease mechanical properties twice as much as porosity, which explained the lack of correlation between X-ray and bend and impact values. Porosity decreased tensile strength only half as much as elongation. Tofaute tested V and X welds, plain carbon and austenitic electrodes in 1/2-inch and 1-inch plate.

Douglass[15] simulated a condition of imperfect fusion by tack welding machined blocks of weld metal in a joint; radiographs revealed no flaw. G. E. Doan and J. E. Waugh explain this by stating that in practice lack of fusion is always accompanied by porosity and slag inclusions, which X-rays detect. Grimm and Wulff[16] show that the effect of unequal cross sections in fillet welds can be eliminated by using wedges of the plate material, a practice recognized by the German standards, and recommend tubular cassettes for T and L welds. Wosdwischenski[17] also describes a method of X-raying fillet welds by placing the film nearly parallel to the X-ray beam, and Da Costa[18] mentions a method for making stereoscopic X-ray films which he does not, however, describe. An anonymous English writer[20] also states that defects in arc welds in 11 1/2 inch thick mild steel can be located to within 1/16 inch by stereoradiographs, but does not describe the method.

Moses[19] used the Laue method to show relief of stress in mild steel welds after stress annealing, and to reveal the grain size of welds in corrosion-resisting steel. An accuracy of 3000 psi is claimed by Möller and Barbers[20] for the back reflection method of determining shrinkage stresses in mild steel welds. They give full experimental details of the methods of calibration and apply their system to a cover strap (MEFI type) welded over a butt weld. A stress of 136,000 psi was observed in the mild steel plate near the normal shear weld of the cover strap.

At the British Iron and Steel Institute Symposium on Welding in 1935, X-ray examination was a minor topic. W. D. Halsey (Vol. II, pages 803–809) pointed out that although X-ray examination of welds is required by the A. S. M. E. Boiler Code (Lloyd's also require an X-ray test of welded pressure vessels), it is confined largely to the fabricating shop and to welds not over 4 1/2 inches thick. It was his opinion and that of the majority that the X-ray is not infallible but is the best non-destructive test at present. R. Bernhard (II, 677–678) stated that the German Railways use the X-ray (up to 300 kv.) on all welded bridges. The tentative specifications for welded plate-girder bridges for the German Railways require that all first grade butt welds in tension must be X-rayed; this means about 50 meters of film in the ordinary bridge. The M. W. Kellogg Co., according to R. K. Hopkins (I, 243–258), require that pressure vessel welds show porosity equal to not more than 2% of plate thickness in X-ray penetrameter tests.

R. A. Stephen (II, 915–923) explains the use of wedges for fillet welds, and discusses the types of defects to be expected in resistance, arc, gas and water-gas welds. He remarks that if defects are so minute that they cannot be detected by X-ray, they certainly cannot be detected by any other non-destructive test. X-rays have shown that most cracks in welds run vertically, according to L. W. Schuster (II, 951). J. B. Johnson (I, 433–441) states that the magnetic test is better than X-rays for welded aircraft tubing, and W. Andrews and W. C. Welsh (II, 307–316) note that burning in high-

alloy steel welds is not detected by X-rays. T. C. R. Shepherd and S. W. Carpenter (II, 161–179) believe that X-rays are practical only for simple, important structures and that a defect must be at least $^1/_{16}$ inch deep in order to be detected. It is F. C. Lea's opinion (II, 939) that the X-ray must be related to some other type of mechanical test to determine the degree of danger of the various types of defects.

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APPENDIX X

Recent Literature on Weld Shrinkage

A—Theoretical and Experimental

Probably the most comprehensive of recent reviews on weld shrinkage has been edited by H. M. Hobart[1] in which brief summaries of recent papers are given by M. F. Sayre, W. M. Wilson and M. Scioletich, and C. R. Whittemore and R. E. Jamieson. The reviews by W. Lohmann and W. Schneider, translated in the American Welding Society Journal, also discuss recent work. The elements of weld shrinkage are discussed by Jensen[2] who presents a number of useful charts on heat evolution and shrinkage measurements in T, butt and lap joints, and who summarizes the results of Bollenrath and others. A somewhat similar review with useful data is given by Rosenthal,[27] and Reeve[25] summarizes thirty major experimental researches, explaining the methods of stress computation employed. A more advanced review of weld shrinkage has been prepared by Buchholtz[3] who describes the mesh method of sawing out small strips previously scribed with reference lines, and who strongly believes that overstressing reduces residual stresses.

A significant advance in the study of weld shrinkage has been made by Boulton and Martin[4] who studied the longitudinal residual stresses in a mild steel plate, 9 feet long, 6 inch x $^3/_5$ inch cross section, after a layer of weld metal (blue asbestos coated mild steel electrodes) had been deposited along one or both edges. The change in length of longitudinal lines scribed on the two faces of each plate was determined by a comparator. The results are in agreement with a theory according to which, as the heat from the traveling arc penetrates into the plate, the steel near the welded edge, being unable to expand freely, sustains a high compressive stress under which it yields plastically. At some instant this plastic yielding penetrates into the plate a maximum distance (compare Shaw and Percival, Section C), beyond which the steel behaves elastically throughout. During the cooling the plate is strained elastically except near the welded edge where the material becomes stressed to the yield point in tension. Equations are derived expressing the longitudinal stress as a function of distance from the welded edge and for the temperature distribution in a plate during welding. The authors believe that transverse stresses such as those arising in butt welds (but, of course, not encountered in their experiments) would not affect the longitudinal stress distribution. Goodier gives a mathematical analysis of shrinkage stresses and conditions for permanent deformation in a locally heated flat strip.

A method for the direct measurement of contraction in butt welds, arc and gas, is described by Harrelson and Slack.[5] It is suggested that the amount of contraction is proportional to the size of the pool of molten metal in the arc crater or under the torch; the larger pools produce more contraction. Harrelson[6] also showed that peening relieves shrinkage stresses up to 50% and suggests alloying the electrode to reduce shrinkage. Bollenrath[7] has continued his experiments on weld shrinkage, the controversial nature of which are discussed in the Lohmann and Schneider review for the first half of 1935. He measured shrinkage stresses in arc and gas welds by the drilled hole and rupture methods. Mies' work[8] is also discussed in detail by Lohmann and Schneider. Using the semi-rigid mesh method with an accuracy estimated to be 1500 psi, he found that maximum longitudinal stresses occur in the tempered zone and reach 50,000 psi in arc and gas butt welds.

An unusual variation of the semi-rigid mesh method for arc welds is described by Liljeblad and Akeson,[21] who present a large number of graphs of stress derived from modulus of elasticity and strain as measured on their welded grids. They apply their results to the shrinkage problems encountered in welding spiders of large rotor frames. Holler, discussing a paper by Eskilson[25] on shrinkage in gas and arc welds delivered at the Twelfth International Congress of Acetylene in London, July 1936, stated that 0.27–0.31 inch electrodes had good shrinkage characteristics, but that electrodes 0.39 inch diam. were definitely inferior.

Ehrt and Kühnelt[26] measured the shrinkage stresses in the interior and on the surface of a shaft (2 feet long, $4^1/_2$ inches diam., 0.66% C) whose surface had been built up by welding (130 amps., 0.16 inch covered electrodes containing 0.08, 0.36 and 0.70% C). The tangential and axial shrinkage stresses were lowest with the

0.70% C electrode. The stresses were measured by observing the changes of length and diameter on drilling the shaft. The highest stresses were in the hardened zone. The authors explain their results by relating them to the difference in coefficient of expansion between low- and high-carbon steels and to the great contraction of the hardened zone.

Shrinkage in 1 inch mild steel welds (heavy coated electrodes) has been measured by Höhn[9] who found that clamping reduces shrinkage but increases cracking. With free plates, V joints give the most distortion, X the least, with U intermediate. The diameter of the electrode has no effect. Large seam cross sections unnecessarily increase distortion in fillet welds. To avoid shrinkage cracks in medium-carbon steels the vicinity of the weld should be preheated to 300° C.

Malisius[10] calculates the shrinkage due to arc welding unconstrained bars on the basis of thermal expansion coefficients, and the shrinkage stresses in constrained bars on the basis of Hooke's Law and shrinkage, in both cases using the average temperature between the plastic range (600° C.) and room temperature. Welding the bars in two layers gave 50% less shrinkage than in one layer. Similar calculations are made for plates and agree with experimental measurements of shrinkage for V and X welds in mild steel up to $^3/_4$ inch thick. In his most recent paper, Malisius gives additional measurements of longitudinal shrinkage and angular distortion for V and X welds in $^1/_2$ inch mild steel, using bare and coated electrodes as well as gas welding. Angular distortion appears to increase with the number of layers.

Using Sachs' method (welding circular patches into disks), Eigenheer[11] measured shrinkage stresses in butt welds in mild steel and low alloy structural steel (0.7 Ni, 0.4 Cu). Arc welding gave higher stresses than gas, preheating and peening still further reducing the stresses in gas welds. W. D. Chapman[12] measured the distortion in $^1/_2$ inch plate for single beads, V, and fillet welds. By increasing the electrode size and speed of welding (6 to 10 gage electrodes) the usual closing tendency in a butt weld may be changed to an opening tendency. Peening the weld causes only partial relief of shrinkage stresses and causes loss of ductility; peening the parent metal alongside the weld is sometimes useful. A number of practical hints on avoiding distortion are also given.

The shrinkage stresses induced in the columns of a railway viaduct by arc welding (type of electrode and amperage not stated but sequences given in full) stiffeners on the flanges were measured by Wilson and Brown.[13] The stresses, which were determined from extensometer readings on gage lines not heated by welding and assumed to have undergone no plastic flow, were 6000 to 11,000 psi average compression in several parts of the columns. In general, live load added a uniform stress to the shrinkage stress. Laboratory tests of strengthened columns of the same type in compression showed that welding did not change the stress resisting capacity as measured by uniform maximum stress in compression. Welding did not distort the test columns ($l/r = 65$); one type of column had interrupted fillets, the other continuous and both had butt welds.

The shrinkage stresses in welded I beams made of nose-profile flanges, according to Gerold and Müller-Stock,[23] are less than in rolled beams of the same dimensions. Beams of low-alloy structural steel developed higher shrinkage stresses than mild steel; the higher yield strength of the former accounted for the difference. Curving a web plate by bending before welding lowered the shrinkage stresses. Siebel and Pfender's method was used. Distortion measurements on welded boxes in $^5/_8$ inch mild steel plate are presented by Polson and Sinfield.[29] Annealing or stress-relieving cold bent plate before welding had no good effect on shrinkage stresses. In giving a theoretical formulation of shrinkage and shrinkage stresses in V butt welds, Koch[14] measures shrinkage stresses as a function of length of weld, breadth of plate, distance between plates, current density, scarf angle, and method of welding. According to Orr,[15] the maximum shrinkage stresses in arc butt welds 9 inch long is 27,000–29,000 psi, in 58 inch length, 9500–16,000 psi, slow welding giving higher stresses than fast. Residual stresses in butt welds made under restraint were reduced 50% by peening, although Robinson, in discussion stated that it is better to cold peen the parent metal than the weld.

The effect of shrinkage stresses on mechanical properties has been the main topic of four investigations. Jamieson[16] found that stress-strain curves for butt welds (U, single pass, covered electrode, unmachined) in unconstrained mild steel plate depart from Hooke's Law very early, indicating high residual stresses locally equal to the yield point. These shrinkage stresses had no serious effect on the tensile strength of the joint (9% less tensile strength than plate metal), but the irregular distribution of the stresses developed unequal distortions which led to tearing at rupture. Using Mathar's drilled-hole method, Müllenhoff[17] showed the effect of longitudinal tensile stress (in steps of 1500–3000 psi up to 14,000 psi) in decreasing the shrinkage stresses in butt welds in mild steel. In gas welds stresses longitudinal and transverse to the weld of 85,000 and 28,000 psi, respectively, were reduced to 14,500 psi. In bare electrode welds a longitudinal shrinkage stress of 64,000 psi was reduced to 36,000 psi; and in covered electrode welds longitudinal and transverse shrinkage stresses of 56,000 and 43,000 psi, respectively, were reduced to 28,000 and 20,000 psi. Stresses above the yield point were found in some specimens but it was stated that plastic flow would not change these stresses. X-ray measurements revealed shrinkage stresses in mild steel welds as high as 136,000 psi.

Sahling (18) found that running a single longitudinal mild steel arc weld bead on a wrought iron bar reduced the tensile strength 10–20%; a single transverse bead caused a reduction of 5% but after grinding down, 15%. With a transverse bead on both sides there was a decrease of 7% which increased to 20% after grinding flush. These decreases were partly attributed to shrinkage stresses. In 35,000 yards of welding for bridge strengthenging only about a yard of shrinkage cracks was detected by X-ray. These cracks usually occurred at the upper ends of corner stiffeners between vertical and horizontal beams; the explanation of the cracks remains uncertain although shrinkage is the basic cause. Kautz[19] found that the pulsating tension fatigue limit of a cold bent bar of low-alloy structural steel with stresses up to the yield point in tension similar to shrinkage stresses in a weld was the same as an unbent bar. Fatigue tests on mild steel drums (not stress-relieved) welded with austenitic electrodes support the belief that shrinkage stresses are released in ductile welds by repeated loading. Kommerell[20] came to the same conclusion on the basis of similar experiments.

Portevin and Séférian[21] present theoretical temperature distribution curves for: 1. a long bar heated at one end; 2. a plate heated in one spot: 3. a butt-welded plate, giving temperature curves for different velocities of welding. All three are based on the differential equation of heat conduction. The theoretical curves were experimentally confirmed using gas (forehand and backhand) and arc (coated electrode) for mild steel (0.1 C), and gas for copper, 18–8, and aluminum. Three-dimensional charts relating temperature

and plate dimensions (length and breadth) are given for several of the above conditions. Although no shrinkage measurements were made, the charts may be of use in shrinkage studies. A patented acoustic method for measuring shrinkage stresses is described by Léonhardt.[22] In this method the change of pitch of a wire stretched between the gage points of an extensometer is measured as the wire contracts or expands with the motion of the points. The device is available in gage lengths of $^3/_4$ inch to 6 inch, the accuracy being 110–190 psi.

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B—Shrinkage from the Field Standpoint

Practical rules for avoiding distortion are given by Bierett:[1] 1. use the smallest possible angle of V to limit the heat; 2. preheat and peen; 3. weld parallel seams at the same time so that shrinkage is not additive; 4. do as little rigid welding as possible. His fundamental criterion is: Would the proposed welding be considered good foundry practice? In the Stahlbau lecture he shows that the heat should be maintained as far behind the electrode as possible to minimize shrinkage stresses. Applying artificial heat under the seam during welding solves the rapid cooling problem and permits the use of U rather than X welds in thick plate (say 2 inch). Turning over, overhead welding, and other troublesome procedure is thus not required, although a single reverse run is advisable. The use of thick electrodes and a few heavy passes rather than many light passes also maintains the heat better and leaves a larger cross section of weld metal to resist shrinkage.

One of the main factors in minimizing distortion is the adoption of intelligent weld sequences. Krüger[2] deals with this subject in an elementary way and recommends step-back welding. If two or more welds in the same piece run in the same direction, Adrian[3] advises in contrast to Bierett that each be welded separately, permitting each to cool to room temperature before commencing the next. If two welds cross, weld that one last which makes for the greater rigidity. Arvidsson[4] outlines the weld sequence for avoiding distortion in long beams. Trimble[5] states that stress-annealing arc-welded road machinery is impracticable but that proper jigs and sequences keep shrinkage within safe limits. He believes there is an intimate connection between shrinkage and grain sizes as well as cooling rate. Multiple layer welding and correct design are the two main factors in reducing shrinkage, according to Bobek.[6] Neese[7] analyzes 15 illustrations of weld distortion and explains weld sequences by means of which distortion might have been avoided. Proper weld sequences and local heating are the means recommended by Kraus[8] to overcome distortion in frames and spoked wheels. In addition to tacking, peening, and proper weld sequence, the deposition of additional beads of metal may be used in order to correct shrinkage, according to an English correspondent.[9]

Another English writer[10] describes in detail the sequence of closing arc welds in large oil storage tanks of mild steel, 34 feet in diameter. Hawley and Merrell[11] found that distortions in floor beams and chords of a steel plate bridge floor caused by shrinkage in the floor plate welds may be eliminated by postponing floor beam connections until the plate welds in the panels were complete, and by peening each pass of a weld before it has cooled. According to an anonymous article in a Swiss welding journal[12], the patching up of corroded pits or cracks in boilers by gas welding does not give rise to serious shrinkage stresses. Schaper,[27] Sahling[31] and Schaechterle[28] review German practice in avoiding shrinkage troubles in structural welding. Milosavljevic[29] outlines the methods of avoiding shrinkage stresses in the first all-welded railway bridge in Jugoslavia, and Nikolaev,[30] who does the same for a Russian bridge, also gives the results of column tests of welded sections. To avoid shrinkage stresses and warpage in the welding of cover plates on girders of an all-welded bascule span, Gardner[35] states that two welders worked on opposite sides, keeping the welding symmetrical and staggering the welding. Gages were used to measure warpage during construction. Wills and Lindemuth[32] discuss methods of avoiding shrinkage stresses in welded heavy machinery.

Preforming as a means of overcoming distortion is lucidly described by Philips[13] who outlines practice in welding pressure vessels at the Cartaret, N. J. plant of the Foster-Wheeler Corporation. The plate is formed to the desired radius even to the edges to be welded. These edges are then bulged outward by means of props adjusted by 50-ton jacks. The amount of expansion that must be created by these props appears to be estimated by trial and error; in a 48 inch drum 12 ft. long the props hold the seam $^1/_2$ inch out of round, and are placed 15 inch to 18 inch from each end to avoid belling of the ends. The U-shaped seam is $^3/_4$ welded, the props removed, two reverse seams are hand welded, and then the remaining top layers are deposited. Correct peening and stress-relieving (1 hour per inch of thickness at 1150° F.), according to Jasper,[25] are the best means for avoiding welding stresses in pressure vessels.

To gas weld thin sheet (0.04–0.08 inch) without distortion, Greger[14] states that the sheets should be placed on a flat grooved cast iron plate, the edges over the groove. A helper should then move a heavy mass such as a die block along the edges and just ahead of the torch to absorb excess heat. The seam must be reverse welded. Hennefeld[15] describes methods for

providing for distortion in gas welding pipes. To weld T's in large pipes the tension side of the head of the T is heated with a torch of the same size as the welding torch to 800° C. over a distance three times the tube diameter. Distortion in welded receivers and beams is also discussed. Wellmann[26] recommends the following root spacings in 90° V butt welded steam pipe to avoid shrinkage butting.

Wall Thickness	Root space
up to 0.20 inch	0.04 to 0.06 inch
0.20 to 0.40 inch	0.06 to 0.08 inch
0.40 to 0.80 inch	0.08 to 0.10 inch

Jigs are a convenient, safe means of avoiding distortion, in welded sheet steel (20–22 SWG), according to Blaha.[16]

Preheating has also been recommended. Totten[17] argues that since shrinkage usually occurs perpendicular to the direction of welding, preheating should be adopted to cause an explanation in this direction, and gives practical instructions toward this end. When dealing with high-tensile steels subject to welding cracks, Bollenrath and Cornelius[34] find that the shrinkage stresses can be decreased only by heating material adjacent to the weld to a dark red or by heat treating before and after welding. Cracks can occur below 250° C. during cooling after welding.

Knez[18] shows the importance of preheating in repairing cracked bells, and believes that shrinkage stresses are as large in brazing as in welding bells. Hettrick[19] emphasizes the importance of preheating by means of charcoal in welding cracked cast iron, and Jones[20] states that heavy castings must be totally preheated to a black heat to avoid distortion and poor alignment. Jones found, however, that if, in the repair of large gears and similar castings, the welding sequence is carefully planned, bronze welding can be used and preheated can sometimes be dispensed with, no distortions occurring.

Slow welding also tends to increase distortion. Harrison[21] states that to gas weld $^{9}/_{16}$ inch steel plate, 35 cu. ft. of acetylene per hour is ample, but for copper of the same thickness 150 cu. ft. of acetylene and 145 cu. ft. of oxygen per hour is required. If less is used the slow heating causes distortion and cracking. If copper welds are peened with a pneumatic caulking hammer at 850–500° C. during cooling, the danger of cracking is eliminated. Nixon[22] infers that welding generators with slow recovery produce high shrinkage stresses for the welding is slower. A disadvantage of covered electrodes compared with cored for low-alloy steels, according to Taschinger[36] of the German Railways, is that the greater heat output of the covered causes greater shrinkage difficulties. The covered electrode is used only for parts that are not rigidly connected. The Focke-Wulf and other tests for detecting the tendency of sheet steel to crack in gas welding are described by Zeyen.[23] Steels with high manganese are relatively free from shrinkage cracking in these tests. Hoffmann[24] traced the cause of shrinkage cracks in gas-welded structural tubing to neglect and bad treatment of the acetylene generator and purifier. Seven rules for avoiding distortion and cracking in aircraft sheet and tube welding are given by Dobson and Taylor.[33] Sherwin[37] discusses a number of practical means for offsetting the effects of shrinkage in cruiser construction. Mechanical straining as a means for stress relieving welded pressure vessels is not desirable, in Dorey's opinion,[38] although research is being carried out on the subject.

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C—Shrinkage at the British Welding Symposium

Shrinkage and shrinkage stresses in welds and their effect on welding procedure formed one of the major topics at the Welding Symposium of the British Iron and Steel Institute in 1935. A long summary of the information and opinions on shrinkage presented at the Symposium has already been made by two English experts, H. W. Townshend and J. L. Adam. In the following summary an attempt is made to summarize the Symposium contributions and discussions on shrinkage, author by author. The summary is in effect an index on shrinkage to the two volumes of the Symposium. The reference (volume and page number) to each contributor is given in parentheses after his name. An asterisk indicates that the entire paper is concerned with the shrinkage question.

Theoretical and Experimental

B. P. Haigh (I, 428–429) summarized available information by stating that the range of temperatures through which the metal cools after gaining rigidity at possibly 600° C. is so great that the successive beads deposited on thick pieces of metal are presumably self-strained in a plastic manner continuously during cooling. When the beads are thin and free from hot shortness no harm ensues and the metal may even be beneficially hardened. Haigh emphasizes the importance in shrinkage calculations of the terms $E\alpha$ (about 350 psi per degree Centigrade for mild steel and $E\alpha/(1-2S)$ S = Poisson's ratio). The slag covering over a weld is an aid to uniform cooling but the absence of shear stresses prevents plastic accommodation to stress. G. M. Shaw (II, 879–895*) showed that in unrestrained plates immediately after butt-welding there is an increase in length in gas welded, but a contraction in arc-welded. After cooling, both specimens had contracted. Distortion measurements are given for specimens simulating butt welds in shell plating and for margin plate attachments, as in ships' structures. Temperature measurements in plate and rivet during strengthening a

riveted joint by welding, and in a simple butt weld are also given. In arc welding the rivet reached 160° C. but in gas welding a joint of the same size, the center of the rivet reached 480° C. G. M. Shaw and L. C. Percival (II, 897–910*) measured the shrinkage stresses in rigidly gripped plates immediately after welding, when cooling was complete, and at intermediate stages, for which a mass of data is presented. In general greater stresses remain finally in arc welds than in gas, and at a certain time during cooling the contraction in the weld is balanced by the expansion in the plates. The shrinkage stresses had only a slight effect on tensile properties. The fatigue tests on a welded boiler drum, described by Haigh, also indicated that fatigue value was little affected by shrinkage stresses.

Unrestrained contraction in weld metal, according to G. Ellson (II, 759–769*), is equivalent to 58,000 lb. per inch of fillet weld. In constraint the weld metal deforms plastically and a shrinkage load of only 5600 per inch of fillet weld was noted. Welding in short lengths with intervening cooling periods did not appreciably affect the shrinkage loads in the fillet. Distortion measurements on beams strengthened by welding are given; the shrinkage stresses (as high as the yield point) associated with these distortions did not affect the ultimate strength of the beams. H. N. Colam and J. D. Watson (II, 715–735*) give the detailed results of measuring the shrinkage stresses in a steel bar by welding longitudinal beads on the surface and subsequently machining. In a beam welded while under high compressive loads, local failure with considerable shortening occurs; with low initial compressive load the yield point is not reached during welding and there is no appreciable shortening. On account of distortion, welding greatly reduces the buckling strength of columns. Results on bars welded while under tensile stress were not conclusive. D. Boyd and G. Cape (II, 39–49*, also *Weld. Engr.* **20,** (7), 19–23, 1935) found the following shrinkage stresses in the weld metal of butt welds:

Bare electrode, one pass 12,000 psi
Bare electrode, two passes 19,000 psi
Coated electrode, one pass 27,000 psi
Coated electrode, two passes 37,000 psi

In plate metal coated produced higher shrinkage stresses than bare, but two passes gave less than a single pass. A large electrode with high current gave higher stresses in plate metal but lower in weld metal than a small electrode with low current; hence, the former practice is better because it gives 25% less stress in the brittle weld metal. A shrinkage of $^1/_8$ inch was observed in each section of a welded pier member 18 ft. long, 8 ft. wide, 2 ft. deep; for such heavy rigid structure their practice is to support the work on steam coils for purposes of preheating, tacking being avoided and the weld sequence being thoroughly planned beforehand.

C. E. Benson and H. Allison (II, 19–27*) measured the relief of internal stress in all-weld-metal (bare and coated electrodes) using a split compression sleeve for measurements. Stress relief up to 90% occurs after 5–6 hours at 550° C. and is over 90% after 5–6 hours at 600° C. The relief is caused by creep. Residual stresses caused by cooling, after stress relief may be expected in welds over 1 inch thick unless slow cooled. J. A. Dorratt (II, 79–87*) showed that the maximum contraction in T joints occurs when a space ($^1/_8$ inch) is left between the chamfered leg and the base plate, arc generally giving less distortion than atomic hydrogen or gas. The amount of energy required to deposit a pound of weld metal is 1.2 kw. hr. for a high-quality covered electrode and 0.86 kw. hr. for bare. Manufacturing methods for avoiding distortion are given. By machining away successive thin layers of a butt weld and noting the accompanying free movement of the parent plates, A. M. Roberts (II, 838–839) found that the surface layers at opposite faces of *V* and *X* joints were in opposite states of stress, that is, tension and compression. The maximum shrinkage stresses occur in the outer layers, which are also most highly stressed in reversed bending fatigue. C. G. Bainbridge (II, 7–18) presents graphs showing that shrinkage and shrinkage stresses are proportional to cooling rate and volume of weld metal (or cross section of weld), as well as to degree of overheating in gas welding. Therefore, the smallest possible angle of opening in *V* and *X* welds should be used.

Practical Aspects of Shrinkage

Two rules with which every one agreed are given by G. H. Moore, Jr. (I, 375–384) for avoiding shrinkage stresses and distortion: 1. allow as much movement to take place as possible during welding; 2. use no excess weld metal and adopt intelligent sequence systems. R. F. Taylor, (I, 459–464) found that shrinkage cracks most frequently occur if welding is done in rigid jigs. Instead of tacking, C. F. Stevens, (I, 599–604) advises clamping or bolting the parts together. In welding gears, T. A. Swindell (I, 657–658) recommends that the spokes be welded in before the rim is closed. He also makes the statement that bare electrodes give less shrinkage cracks in plates up to 7 inch thick than any grade of covered electrodes; several contributors were of the opposite opinion in the matter. One contributor stated that internal stress relief in bare electrode welds was afforded by numerous fine micro-cracks. The Director of Naval Construction (II, 67–77) advises that as much shop welding be done as possible because welding sequences are more difficult to plan on the ship and the welding itself is also more difficult. N. M. Hunter (II, 115–118) found that distortion in ship-welding is not so great in heavy plate (over $^3/_8$ inch), as in light parts. The sequences recommended by the German Committee for Technical Education on the basis of the step-back process are not satisfactory in practice, according to G. Erber (II, 281), who recommends tacking with the carbon arc. Complete instructions for avoiding distortion in light structural steel work are given by P. Mitchell and H. Martin (II, 139–154). D. Ross, (I, 289–298) found that contraction stresses in 42 inch pipe could be reduced to a minimum by instructing the welder on the basis of measurements made continuously during welding.

Shrinkage cracks are very likely to occur in the weld metal during cooling, according to D. Arvidsson (I, 31–42), if the yield point of the plate is above the ultimate strength of the weld metal. W. Bennett (II, 276) raises the question whether the weld metal should be stronger or weaker than the plate in order that shrinkage stresses may be eliminated by plastic flow. According to W. H. Hatfield (II, 652), it is impossible to give precise figures for the safe maximum amount of shrinkage stresses in ship welding on account of the complexity of stress distribution. He also believes that shrinkage stresses are relieved by repeated over-stressing, but to what extent he did not care to say, M. Roš and A. Eichinger (II, 843–866) list shrinkage stresses as a cause of failure of welds in high-carbon and alloy steels, but they consider shrinkage stresses unimportant in mild steel unless exceptionally high. The latter view was regarded as dangerous by other contributors. A. B. Kinzel (I, 403 and II, 424–425) states that local stress-relieving is a failure. It was G. Zeriali's experience (I, 609–618) that ventilator fan wheels could

not be gas welded on account of distortion; arc welding was satisfactory. Shrinkage cracks in welded steel castings, according to A. M. Roberts (I, 635–645), are due to hot shortness (sulphur segregation) in the casting, but he was not concurred in this opinion by another contributor.

In their review of the Symposium papers, H. W. Townshend and J. L. Adams state that time alone may eliminate shrinkage stresses. A plate pulled cold into a curved position, welded, and after several weeks released, retained the initial curvature. Their experience is that weaving produces high stresses in fillet welds. The general conclusion of the lengthy discussions provoked by Townshend and Adam's review is that there are fewer facts known about shrinkage stresses than is generally believed. It remains a question whether fatigue or impact dissipates shrinkage stresses; it is known that static over-stressing is effective in this respect. J. H. Paterson mentions that welding stresses are probably triaxial rather than linear or plane as most investigators assume. C. G. Gough points out that measurements of butt weld contractions did not at all agree with calculations on the basis of thermal expansion. The superimposed stresses produced by peening were often as dangerous as the shrinkage stresses themselves.

APPENDIX XI

Recent Literature on Stress Distribution in Welded Joints

Theoretical

An extensive review of literature (1933–1935) on stress distribution in welded joints has been edited by H. M. Hobart,[1] the reviewers being M. F. Sayre, J. H. Zimmerman, A. Solakian, and W. M. Wilson and M. Scioletich. Klöppel[2] also reviews work by Bierett, Hertwig and others on stress concentrations in welds. Lyse and Schreiner[3] determined the stress distribution in welded seat angle connections mathematically and experimentally, and Lyse and Stewart found that the results were in good agreement with photoelastic studies. Schreiner also determined the stress distribution in fillet welds in bending by means of strain gages. It was found that the strain at the root of the weld is about twice the average strain and three times that at the edge of the weld; furthermore, the stress is practically uniformly distributed over the weld cross section at the loading which just caused scaling of the white wash on the surface of the weld. The stress distribution in welded seams inclined 45° to the axis of load is discussed mathematically by Roš and Eichinger.[4] Höhn[5] has measured the stresses in combined riveted and welded joints by means of strain gages. Blomberg[6] subjected *X* butt welds and welded *T* joints with incomplete penetration to tensile stress, and showed, by means of a ruled mesh on the specimens, that plate as well as weld undergoes deformation. The review of bend testing by Sayre[7] contains a great deal of information on the strain distribution in butt welds in static bending.

Using the "cracked varnish" method, Kayser and Herzog[8] illustrate the stress distribution in: a welded angle connection, butt welds, butt welds with cover plates, end and side fillet welds, riveted joint strengthened by welding, and the corner of a welded web frame. Detailed numerical data are given only for the last example. The tests were performed on full scale structural steel, cracks occurring in the coating of varnish perpendicular to the maximum tensile stress. Neuber[9] shows that the empirical constant in Hovgaard's equation for the stress distribution in welds is dependent on the dimensions of the weld and is, therefore, not a theoretical elastic constant. In Neuber's analysis the only constant involved is the ratio of the moduli of elasticity in shear and in normal stress. Schuster[10] again recommends the use of rubber models for studying the strain distribution in butt welds. The stress distribution in the standard German round-notched tensile specimen for butt welds is mapped by Grüning and Hoffmann,[11] using strain gage measurements on a large steel model. A stress of 1.27 times the average stress occurs at the edge of the minimum section. Isaacs[35] has made a mathematical investigation of the stress distribution in side fillet welds taking account of relative motion between the two edges of the weld. He made torsion tests to determine the shear strength of all-weld-metal (arc) and also made strain measurements on rubber models of side fillets. A soap-film apparatus was constructed but was found impractical. Isaacs presents charts to determine the type of fillet weld to be used for best stress distribution depending on the ratios of the yield strengths of deposited to base metals. He concludes that side fillets should be run to the ends or edges of members where possible, and that side fillets should be used in combination with end fillets.

Photoelastic

The most recent contribution by Solakian[35] to the photoelastic study of welds deals with end fillet welds. It was found that defective penetration greatly increases the maximum stress at the root of the fillet.

In his paper at the British Welding Symposium in 1935 Coker[12] shows the elastic stress distribution in end fillet welds and in butt welds with defects. An appendix to this paper contains a discussion by A. E. H. Love of the mathematical theory of stress distribution around a cavity in an infinite tension number. Coker has also given a complete analysis of a butt weld of which only one plate is beveled. The construction of an inexpensive mirror polarizer and its application to a few welded joints is described by E. W. P. Smith.[13] Baud[14] gives the principal stress trajectories and maximum stress concentrations in a *T* joint with a slot. The maximum stress concentrations in *V* and *X* butt welds is 1.76 and 1.58, respectively, according to photoelastic investigations by A. M. Roberts.[15] The A. W. S. Tentative Fusion Welding Code,[16] is illustrated by a number of photographs of photoelastic models of fillet and butt welds and welded structures under stress.

Structural

The stress distribution over the panels of a welded bulkhead was determined during a hydrostatic pressure test by Spackman[17] using strain gages. A strain study was also made by means of a coating of whitewash on the outside surface of the bulkhead. Klebowski[37] has calculated the stress distribution in welded pressure vessels using the Huber-Mises-Hencky strain-energy hypothesis. Grover[18] subjected two full-size welded built-up plate girders, 54 inch deep, 27 ft. long to a bend test to destruction and found that a favorable stress distribution was developed as revealed by strain gages and whitewash coating. Bending tests by Haigh[36] on channels 45 in. long, 6 in. wide, arc fillet welded at 90° showed that deflections in the elastic region were greater than calculated, but the yield strength (50% increase in slope of load-deflection curve) was fully equal to the theoretical value. Bühler and Buchholtz[19] mapped the stress distribution in the top and bottom of

the lower flange of an I beam (51 inch span) with and without welded stiffeners; extensometers were used. Bryla[20] has also studied the effect of welded stiffeners on stresses in I beams. The stress distribution in the webs of riveted beams strengthened by arc welding was determined by Ellson[21] by means of stress measurements and of a mesh chalked on the webs. Everall and Berridge,[22] using strain gages, determined the stress distribution in riveted triangulated girders strengthened by arc welding.

The stress distribution in welded beams as affecting design calculations is discussed by Patton and Gorbunow[23] and by a number of writers in structural engineering publications, as for example, Wreden and Klingberg. Beaufoy[24] uses load-deflection tests on celluloid models to determine the stress and moment distribution in a welded steel arch rib roof and in rigid frames of several common types. Le Ricolais[25] gives calculations on the strength in compression, bending and torsion of corrugated spot-welded sheet metal spars and similar products. Hänchen[26] gives moment diagrams for a number of types of welded beams, and von Abo[27] has determined load deflection diagrams of three types of fusion-welded rail joints. Helsby, Hamann and Samuely and Lyse,[28] among others, state that the rigidity of welded supports produces partially restrained conditions with consequent reduction in maximum bending moment over simple supports, but quantitative values of the degree of restraint are not given.

The methods of design of welded Vierendeel trusses presuppose that the section is non-deformable and that the stresses are uniformly distributed in the flanges. As A. V.[34] points out, Dustin did not find the rigid condition in his tests and showed correctly that outstanding flanges must be made thicker and with smaller unsupported breadth (lower equivalent slenderness ratio) than calculations indicate. Since the welds must also be thicker, the rigidity is further increased.

In developing a theory for the stability of compression flanges in through-bridge plate girders, Proctor[29] states that all-welded construction permits more accurate application of the theory because no slip occurs, but that there will be no relief due to slip from secondary stress within the yield point. However, Prof. J. H. Baker, summarizing the final report of the British Steel Structures Research Committee, advises that "when any departure is made from the usual method of fabrication or layout, such as when welding is used to connect the members, it would be unwise to allow the use of any other method of design than that now presented."

A number of general recommendations have been made relating stress concentration in welds to their strength and design. Thus, Thum[30] has found that the effect of abrupt changes of cross section in welds is to create stress concentrations and to lower fatigue values. In Dumas' opinion,[31] plastic flow under static load equalizes stress concentrations in welds but under pulsating load the concentrations do not disappear but occur during every cycle of load. Braunfisch[32] illustrates the arrangement of welds to obtain the most favorable stress distribution, and Daeves[33] states that the repeated impact test reveals good or bad stress distribution in welded joints.

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APPENDIX XII

Recent Literature on Corrosion on Welds

Among the best corrosion tests for welds in mild steel is that devised by Hensel and Williams,[1] which is an alternate immersion test using tensile specimens. Reproducible results were obtained in normal HCl with low-carbon steel welded with bare and coated electrodes. Structural heterogeneity as revealed by microstructure affected corrosion properties adversely. Roux[2] found that the change of potential with time of the cell; parent metal—weld metal in various electrolytes provides a good indication of the corrosion properties of welds. A coloriscopic test using a pH indicator, Prot[3] shows, gives a quick indication of areas prone to corrosion attack, and agrees with service tests of welded Duralumin tubing. Hunsicker[4] reports methods of testing V welds in $^3/_8$ inch electrolytic copper with various mechanical and heat treatments in acetic acid (100%) up to the boiling point and in the vapor of acetic acid with and without admixture of air. Reproducible results were difficult to obtain. Annealing at 600° C. was good, but at 800–900° C. was bad for corrosion resistance. In the early stages of the test the corrosion rate rapidly decreased but after two hours a constant rate was attained. Potential measurements in acetic acid showed that a weld with 0.6% Ni had a higher potential than a pure copper weld with respect to parent metal but that 0.8% Ag reversed the polarity so that the weld became positive. Thum[5] recommends three types of tests for welds in corrosion-resistant materials: 1. wedge-shaped specimen in salt-spray (100 hrs. in fog of 4% sea salt solution); 2. continuous acid immersion (chemical corrosion indicated by weight loss during five 48 hrs. periods in boiling 65% HNO_3); 3. intercrystalline corrosion estimated by change in electric conductivity of welded specimen after boiling in a solution of 13 gm. $CuSO_4$, $5H_2O$, 47 cc. H_2SO_4 per liter. The corrosion resistance of coated electrode welds in 4–6% Cr steel

preheated to 500–600° F. is equal to parent metal. According to Spraragen,[6] laboratory tests such as the salt spray do not agree with service corrosion results in welded ship steel. Poste,[10] who suggests that the A. S. T. M. tentative specification for corrosion testing 18–8 in nitric acid be applied to welds, states that the alternate immersion test is difficult to standardize, and suggests a corrosion fatigue test to reveal intergranular penetration in stainless alloys (no details).

Good general reviews of the corrosion of welds are given by Moses[7] and Leroy and Bonnot.[8] The former gives results of all-weld-metal (no details) corrosion tests of low-carbon steel in H_2SO_4, HCl, NH_3 and other reagents which showed that, in general, weld metal is not inferior to plate metal and that stress-relief improves corrosion resistance. A fine grained deposit, such as that obtained with multiple-layer shielded arc, is less susceptible to intergranular corrosion than coarse grained. Ferroxyl indicator tests of carbon arc welds revealed no difference in potential due to difference in grain size. Leroy and Bonnot consider that coated electrode welds have generally better corrosion resistance than bare and that the presence of flux in any weld, mild steel, aluminum, or 18–8, is damaging to corrosion resistance. They state that it is debatable whether carburization of 18–8 during acetylene welding is a factor in corrosion resistance, (although Inglis and Andrews[21] appear to have proved that local carburization in gas welding is definitely harmful), and that blow holes are particularly serious in the corrosion of copper welds. Naumov[9] found that welds made with coated electrodes had the same chemical behavior as parent metal in cellulose sulfate boilers. Laute[11] showed that the corrosion fatigue limit (rotating beam, 500 cps.) of arc-welded mild and gas-welded copper was considerably below parent metal. But Roš and Eichinger[12] found that tap water corrosion has no effect on the fatigue limit of gas and arc welds in mild steel.

The corrosion of welds in mild steel, such as ship and boiler plate, has been studied by several investigators, but several contributors to the I. & S. I. Symposium in 1935, who asked for information concerning the effects of rough texture, galvanic action, and moisture pockets on the corrosion of welds, received no reply. It was pointed out, however, that welding especially with locked seams overcame the corrosion difficulty associated with riveted joints. Brillié, Leroy and Roux[20] performed constant and alternate immersion tests of two plain-carbon steels (0.05 and 0.33% C), a 0.4 Cu steel, and a steel containing 0.5 Cr, 0.6 Cu, welded by oxyacetylene and arc. The solutions were 3% NaCl + 1% boric acid, and 20% H_2SO_4. The same filler rod gave the same results on all four steels. The criteria of corrosion were appearance and decrease in thickness; the constant immersion tests in H_2SO_4 were of 48-hr. duration, the alternate in saline solution lasted 6 days. Schoenmaker, discussing this paper, stated that his tests showed that all-weld-metal specimens of 0.5 Cu steel had about the same corrosion resistance as base metal. His tests indicated that the junction zone was the critical region in corrosion.

The Corrosion Committee of the British Iron and Steel Institute[13] report tests on unmachined welds in mild steel made with various electrodes (no details) and exposed to sea air, intermittent wind and sea water, and total immersion in sea water. Welding had practically no effect on corrosion resistance even with brass in contact with the total immersion specimens. Zechnowitzer[14] found that best corrosion resistance to artificial sea water (3.7% NaCl) was obtained in ship steel (low in P and S) when welded with copper-containing electrodes without overheating. Shaw[15] observed no appreciable reduction in plate or weld thickness in two arc-welded vessels after the shell plating had been immersed in salt water for four years.

The corrosion of welded boiler plate in a boiling solution (atmospheric pressure) of salt and calcium and magnesium sulphate has been studied by Hatfield,[16] who used pickled, unmachined gas and arc welded specimens. The results, quoted as grams loss, were variable, the welds appearing to have a slightly greater loss than the unwelded plate after four weeks, but this may be explained by the greater exposed area of the welded specimens, which were only 3 x $^3/_4$ x $^1/_2$ in. thick. There was no indication of local action at the junction zone or of pitting in the welds. Further, there was no advantage in annealing or normalizing the plate before welding, and no difference between bare and coated electrodes although gas welds were slightly more resistant than arc. Frantz[17] states that if the overheated areas of boiler welds are exposed, local action may be expected. Stress-corrosion tests of normalized and stress-annealed V butt welds in low-carbon steel for 32 hours in a boiling corroding medium (composition not stated) are reported in a German magazine.[19] Serious intergranular cracking occurred in all normalized welds whereas the stress-annealed welds were unaffected. Isgaryschev and Sidoroschin[18] found that welded boiler plate has better corrosion resistance than riveted and recommend that the weld layers in contact with the corroding liquid be deposited by gas, thus giving good corrosion resistance and low shrinkage stresses.

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Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators

Published for Purpose of Eliciting Comments, Criticisms and Suggestions

AMERICAN WELDING SOCIETY
33 West 39th Street
New York City

Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators

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FOREWORD

To the Board of Directors:

In the development of fusion welding applications, progress has been made only by offering to the user definite assurance of the integrity of the welds. The most positive determination for this is, of course, the non-destructive exploration or test of the welded joint, but where that form of test does not appear to be warranted, the plan of qualifying the welding operator by tests of welds made by him is by common consent regarded as the most effective safeguard for weld quality. In fact, most of the welding codes and specifications recently formulated contain more or less complete requirements for such qualification tests, some of which are applicable even when non-destructive tests of the welds are called for.

Due to the varying conditions under which these qualification practices have arisen, however, there appears to be little uniformity of plan or purpose among them and the variations, involving tests of both process and operators, have caused considerable confusion. Neither the manufacturers or contractors nor the welding operators appear to be satisfied with present practices. It is, therefore, the hope that the recommendations here submitted will tend to eliminate further confusion by correlating the various qualification tests and merging them into one uniform set of rules.

Purpose of Qualification Tests

The quality of a fusion welded joint will be determined by the specific process used and by the ability of the welding operator to apply that process. Predictable results as to the physical properties and soundness of welded joints can be secured only by strict adherence to a fixed procedure of welding that has been properly investigated. It cannot be expected that good results will be obtained even by careful and painstaking workmen if poor materials, inadequate or wornout equipment are used, or if fundamentally improper methods are pursued. Nor can the purpose of welding be attained by the mere adoption of a carefully outlined process of welding if the workmen are not adequately trained to follow that process, and properly supervised to be certain that all essential details of the specific process are followed.

In fusion welding the physical properties of the weld metal, such as tensile strength and ductility, will be determined by the particular process of welding that is used. The reliability of the welded joint will be determined by the degree to which that weld metal is kept free of foreign materials, such as slag, and by the degree to which it is fused to the base material. Under a fixed procedure of welding these two latter factors are the only ones over which the welding operator has control. It is considered unnecessary, therefore, to test every operator for tensile strength and ductility. It is the belief of your Committee that the first step in welding must be the adoption of a procedure of welding in which all essential variables are fixed within definite limits. This procedure should then be investigated to determine whether it will produce welds with the desired tensile strength, ductility and soundness. Soundness tests are included in the investigation of a welding process since there have been many instances wherein lack of soundness has been attributed to the inability of the operator when the difficulty lay in the fundamentals of the process.

Having established that a given process is satisfactory it is then necessary, for the qualification of welding operators, to determine only their ability to produce sound welds by that process. With the above principles in mind, these Rules require testing for tensile strength, ductility and soundness in the investigation of a process, but call for soundness tests only in the qualification of an operator. In Part I there is given the method to be pursued in investigating and qualifying a welding process, while Part II outlines the procedure for qualification of an operator who applies that process.

Responsibility

The question of responsibility for the integrity of the welding application enters into every contract for fusion welding and one of the greatest difficulties at the present time is the proprietary interest that is taken in the welding work by many of the welding operators. It is the conviction of this Committee that there are so many essential factors involved in the successful application of fusion welding, embracing such items as quality of filler metal, adaptability of the welding process and equipment, facilities provided for preparing the work, etc., that the manufacturer or contractor alone should be expected to be responsible for the integrity of the finished weld. It should always be borne in mind that it is the manufacturer or contractor who is financially responsible for the quality of the welding performed and that in the case of failure thereof the welding operator assumes no share of the financial burden. In these Rules, therefore, the entire responsibility for quality of the welding performed will be assumed to lie with the manufacturer or contractor.

Critical Values and Inspection

Your Committee has found it impossible to include in these Rules any criteria which test specimens shall meet or any requirements for inspection or periodic requalification of operators. These factors will depend upon the application of a welding process and their determination lies with the various code authorities who incorporate these Rules into their code. A degree of tensile strength, ductility and soundness which will be entirely adequate for one application may be entirely inadequate for another. Some codes may require rigid inspection by quasi-official inspectors, whereas other code bodies may consider inspection unnecessary. However, competent and unbiased inspection is considered desirable for procedure qualification and qualification of operators. In the case of welding applications where mandatory construction codes or regulations are effective the type of inspection specified therein should govern in the qualification tests. For welding applications where no mandatory requirements are involved the best results will be obtained from inspection by an inspection agency, or by a qualified representative of the purchaser, or by an official of the employing company that is interested in the quality of the product. The purpose of this inspection is to make sure that the test specimens are truly representative of the welding work in question and that the test results are authentic. Only in this manner can the test results be given the standard that is desired by the manufacturer or the contractor.

The matter of periodic requalification tests or period of effectiveness of an operator's qualification has not been covered in detail since your Committee believes there is doubt as to the value of such tests as ordinarily conducted. It is believed that when an operator has been properly trained and has demonstrated his ability to produce sound welds, he will, within reasonable limits, continue to do good work if he is continuously employed and if his working conditions are proper. Requalification tests are open to criticism in that they are generally known to be tests, and it is natural that the operator will extend himself when undergoing such tests. A procedure that is more to the point is an occasional examination, destructive or non-destructive, of an object which the welding operator has fabricated. The knowledge that any weld that is made may be subjected to searching examination will have a most salutary affect upon the quality of work of any operator and cause him to apply himself at all times. However, if periodic requalification tests are to be given they should be of the same nature as the initial qualification test outlined in these rules, and should be given without notice to the operator rather than at stated periods.

How frequently such retests should be made is a matter that should be decided by the various code bodies.

Respectfully submitted,

COMMITTEE ON CORRELATION OF REQUIREMENTS OF EXISTING CODES RELATING TO TESTS OF WELDING OPERATORS.

C. W. OBERT, *Chairman*

C. W. BRYAN, JR.	F. EDER	A. F. KEOGH
E. CHAPMAN	E. H. EWERTZ	J. W. OWENS
R. W. CLARK	GEO T. HORTON	H. S. SMITH
E. L. DURKEE	W. D. HALSEY	A. VOGEL

Rules for Qualification of Welding Process and Testing of Welding Operators

General

These rules are not intended to apply to the non-ferrous materials. The test requirements are intended to apply only to low carbon non-alloy steels.

Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding process to determine its suitability to ensure welds which will meet the required tests, but also of the welding operators to determine their ability to properly apply the procedure.

Rules for the qualification of a welding process and procedure are given in Part I, below. Rules for the testing operators follow in Part II.

Part I—Qualification for Welding Process

1. Limitation of Variables

For the qualification of each welding process the manufacturer shall establish and record as a *Process Specification*, the definite limits of all essential variables involved, and in the investigation of each welding process the Process Specification shall be followed. Suggested forms for Process Specifications are given in the Appendix.

2. Types of Test and Purpose

The types of tests outlined below are to determine the tensile strength, ductility and lack of soundness of welded joints made under a given Process Specification. Whereas some of the required tests are intended solely for the determination of lack of soundness, all types of test specimens shall be examined for lack of soundness if failure occurs in the welded joint. Lack of fusion or root penetration, cracks, slag and gas inclusions constitute lack of soundness (see Appendix). The tests required are as follows:

A. For all types of Welded Butt Joints.

- (*a*) Reduced Section Tensile Test—For tensile strength and lack of soundness of welded joints.
- (*b*) Free Bent Test—For ductility of weld metal in welded joints and lack of soundness of joint.
- (*c*) Root Break Test—For lack of soundness of welded joints.
- (*d*) Side Break Test—For lack of soundness of welded joints.
- (*e*) Nick Break Test—For lack of soundness of weld metal in welded joints.

B. For all types of Fillet Welded Joints.

- (*a*) Longitudinal or Transverse Shear Test—For shear strength of fillet welds and lack of soundness of joints.
- (*b*) Free Bend Test—For ductility of weld metal in welded joints.
- (*c*) Fillet Weld Break Test—For lack of soundness of welded joints.

C. For special types of Welded Joints.

- (*a*) Reduced Section Tensile Test—For tensile strength.
- (*b*) Free Bend Test—For ductility of weld metal in welded joints.
- (*c*) Etch Test—For lack of soundness of welded joint where none of the tests for lack of soundness of butt or fillet welded joints can be made.

3. Base Material and Its Preparation

The base material and its preparation for welding shall comply with the Process Specification. For all types of welded joints the length of the Weld and the dimensions of the base material shall be such as to provide sufficient material for the test specimens called for hereinafter.

4. Position of Test Welds

A. Classification of Position.

All welds that will be encountered in actual construction, except butt welds in pipe, shall be classified as being in the (1) Flat, (2) Horizontal, (3) Vertical or (4) Overhead Position depending upon the manner in which the weld metal must be deposited.

B. Butt Joints in Plate.

In making the test welds for butt joints in plate, the test plates shall be placed in an approximately horizontal plane for the (1) Flat and (4) Overhead Positions, and in an approximately vertical plane for the (2) Horizontal and (3) Vertical Positions. The weld metal shall be deposited from the upper side of the test plates for the Flat Position, and from the under side thereof for the Overhead Position. The test welds shall be run horizontally for the Horizontal Position and vertically for the Vertical Position.

C. Butt Joints in Pipe.

Butt joints in pipe shall be classified as (1) horizontal rolled; (2) horizontal fixed; (3) vertical fixed.

If a process is investigated for the horizontal fixed position it need not be repeated for the horizontal rolled position, provided the procedure for the welding is the same.

If a process is investigated for butt joints in plate for all positions as outlined under 4B, above, the investigation need not be repeated in pipe.

The axis of the pipe shall be approximately horizontal for test welds to be made in positions (1) horizontal rolled, and (2) horizontal fixed, and the pipe shall be rolled for (1) and shall not be rolled for (2).

The axis of the pipe shall be approximately vertical for test welds to be made in position (3) vertical fixed, and the pipe shall not be turned while welding.

D. Fillet Welded Joints

(*a*) A fillet weld made in such a position that the throat is in an approximately vertical plane, and the axis of the weld is approximately horizontal, shall be classified as position (1) flat, and the test plates shall be so placed as to simulate this condition.

(*b*) A fillet weld one leg of which is on the upper side of an approximately horizontal surface and the other leg is in an approximately vertical plane, with the axis of the weld approximately horizontal, shall be classified as being in position (2) horizontal. The test plates for this position shall be placed one horizontally and the other vertically and the test welds deposited on the upper side of the horizontal surface and against the vertical surface.

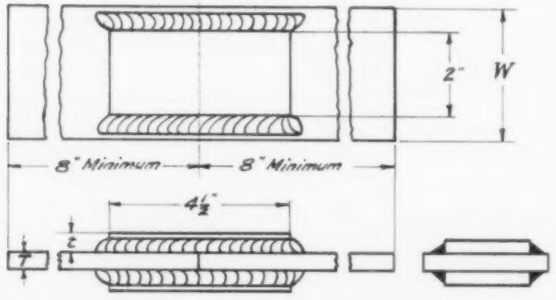
(*c*) A fillet weld one leg of which is on the underside of an approximately horizontal surface and the other leg is in an approximately vertical plane, with the axis of the weld approximately horizontal, shall be classified as being in position (4) overhead. The test plates for this position shall be placed one horizontally and the other vertically, and the test welds deposited on the under side of the horizontal surface and against the vertical surface.

(*d*) Any fillet weld whose axis is at an angle of more than 45 degrees with a horizontal plane shall be classified as being in position (3) vertical. The test plates for this position shall be placed in a vertical plane and the test welds run vertically.

5. *Number, Type and Size of Test Welds*

A. Butt Joints in Plate.

(*a*) For butt joints in plate two test welds shall be made for each process and position to be used in construction. One test weld shall be made in the minimum thickness and one in the maximum thickness of material that will be used in construction except that the thickness need not exceed $1^1/_2$ inches.



Fillet Weld Size		1/8"	1/4"	3/8"	1/2"
Thickness	t	3/8"	3/4"	1"	1½"
Thickness	T	3/8"	1/2"	3/4"	1"
Width	W	3"	3"	3"	3¾"

Fig. 1a—Longitudinal Shear Test Weld

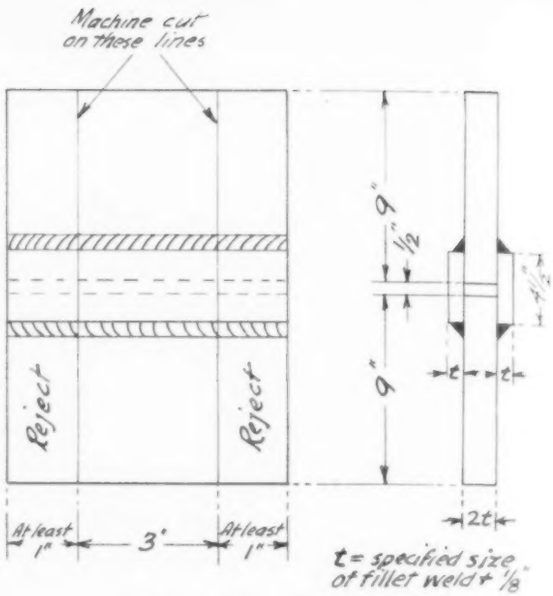


Fig. 1b—Transverse Shear Test Weld

B. Butt Joints in Pipe.

(*a*) For butt joints in pipe two test welds shall be made for each process and position to be used in construction. One test weld shall be made in the minimum pipe wall thickness and one in the maximum pipe wall thickness to be used in construction, except that the thickness need not exceed $1^1/_2$ inches.

C. Fillet Welded Joints.

(*a*) For fillet welded joints two longitudinal or two transverse shear and two break test welds shall be made for each process and position to be used in construction. For each type of test weld one shall be made with the maximum size single pass fillet weld and one with the minimum size multiple pass fillet weld that will be used in construction.

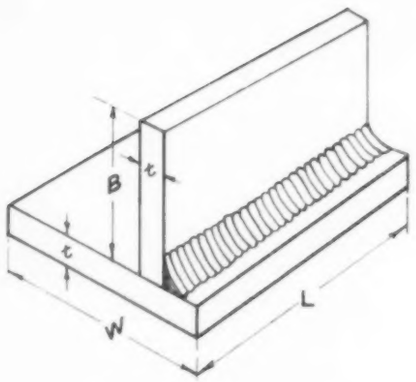
(*b*) The longitudinal shear test weld shall be made as shown in Fig. 1*a*, and the transverse shear test as shown in Fig. 1*b*.

(*c*) The fillet weld break test shall be made as shown in Fig. 2 and the thickness of the base material shall be at least $^1/_8$ inch greater than the size of the fillet.

Note: In addition to the above tests and if fillet welds only are being investigated, two single welded butt test welds shall be made for each process and position to be used in construction. One test weld shall be made in a plate thickness equal to the throat dimension of the maximum size single pass fillet weld and one in a plate thickness equal to the throat dimension of the minimum size multiple pass fillet weld that will be used in construction.

D. Special Types of Welded Joints.

In addition to the above tests, for either or both butt or fillet welded joints, and wherever the conditions for welding in actual construc-



B = Approximately 4"

L = Not less than 4" and need not exceed 6"

W = Approximately 5"

t = Size of weld + $\frac{1}{8}$"

Length of weld should not be less than L − 1"

Fig. 2—Fillet Weld Break Test Weld

tion are such that it may be difficult, because of inaccessibility, to make a sound welded joint, one sample joint simulating the actual construction shall be made. The welding of such joints shall be done in the same position and within the same restricted space for the welding operator as will apply in actual construction. The thickness of the base material and the throat of the weld shall be the maximum that will be used in construction except that neither need exceed $1\frac{1}{2}$ inches.

6. Welding Procedure

The welding procedure shall comply in all respects with the Process Specification.

7. Test Specimens—Number, Type and Preparation

(*a*) Butt Welded Joints. From each test weld there shall be taken the following test specimens which shall be prepared for testing as shown in the figures referred to:

For Single Welded Butt Joints in Plate:

Two Reduced Section Tensile Specimens	Fig. 3
Two Free Bend Specimens	Fig. 4
Two Root Break Specimens	Fig. 5
Two Side Break Specimens	Fig. 6
Two Nick Break Specimens	Fig. 7

For Double Welded Butt Joints in Plate:

Two Reduced Section Tensile Specimens	Fig. 3
Four Free Bend Specimens	Fig. 4
Two Side Break Specimens	Fig. 6
Two Nick Break Specimens	Fig. 7

For Welded Butt Joints in Pipe:

Two Reduced Section Tensile Specimens	Fig. 8
Two Free Bend Specimens	Fig. 9
Two Root Break Specimens (not required where backing up strip is used)	Fig. 10
Two Side Break Specimens	Fig. 11
Two Nick Break Specimens	Fig. 12
Two Etch Specimens (required only when backing up strip is used)	

The test specimen (except for horizontal fixed position welds in pipe) shall be removed in the order given above except that no two specimens of the same type shall be removed adjacent to each other. For horizontal fixed position welds the test specimen shall be removed as shown in Fig. 13.

(*b*) Fillet Welded Joints. Each longitudinal shear test weld shall be prepared for testing as shown in Fig. 14*a*. Each transverse shear test specimen shall be prepared for testing as shown in Fig. 14*b*.

From each single welded butt test weld there shall be taken two Free Bend Test Specimens which shall be prepared for testing as shown in Fig. 4. The fillet break test welds need no preparation for testing.

(*c*) Special Types of Welded Joints. From each test weld there shall be removed, at such locations as will best reveal lack of soundness of the welded joint, not less than three etch test specimens. These specimens shall be a cross section of the welded joint including at least $\frac{1}{2}$ inch of base material on each side of the weld. The width of such specimens in the direction of the weld need not exceed $\frac{1}{4}$ inch.

8. Method of Testing Specimens

(*a*) Reduced Section Tensile Specimens. Before testing the width, thickness and cross-sectional area at the weld shall be recorded. Each specimen shall be loaded in tension at a uniform rate until fracture occurs, and the maximum load in pounds shall be recorded. The tensile strength shall be recorded as the maximum load divided by the cross-sectional area as above recorded. If failure

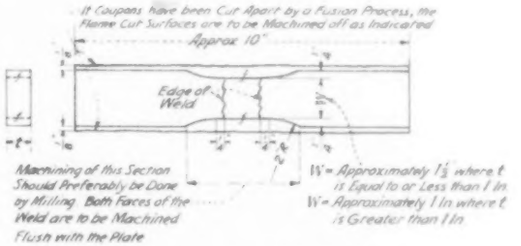
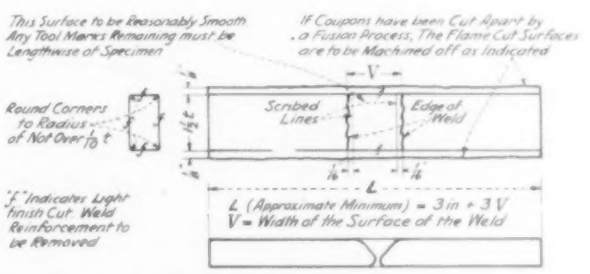

If Coupons have been Cut Apart by a Fusion Process, the Flame Cut Surfaces are to be Machined off as Indicated
Approx 10"
Edge of Weld
Machining of this Section Should Preferably be Done by Milling. Both Faces of the Weld are to be Machined Flush with the Plate
W = Approximately 1½ where t is Equal to or Less than 1 in
W = Approximately 1 in where t is Greater than 1 in

Fig. 3—Reduced Section Tensile Test Specimen


This Surface to be Reasonably Smooth Any Tool Marks Remaining must be Lengthwise of Specimen
If Coupons have been Cut Apart by a Fusion Process, The Flame Cut Surfaces are to be Machined off as Indicated
Round Corners to Radius of Not Over 1/10 t
Scribed Lines
Edge of Weld
"F" Indicates Light Finish Cut. Weld Reinforcement to be Removed
L (Approximate Minimum) = 3 in + 3 V
V = Width of the Surface of the Weld

The Length of The Bend Specimen is Immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandatory

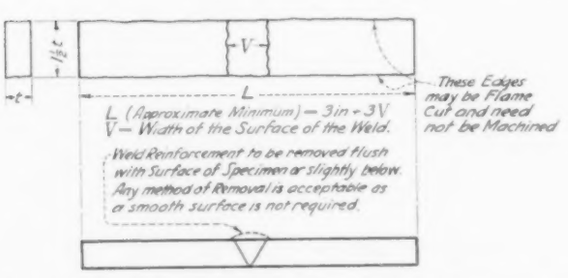
Fig. 4—Free Bend Test Specimen

occurs in the welded joint, the fractured surfaces shall be examined for lack of soundness.

(*b*) Free Bend Test Specimens. For single welded butt joints the scribed lines shown in Fig. 4 shall be on the surface opposite the root of the weld. For double welded butt joints the scribed lines on two of the specimens shall be on one surface of the weld and on the other two specimens shall be on the opposite surface of the weld. The distance between the scribed lines is to be measured in $^1/_{100}$ part of an inch and this measurement recorded as the initial gage length.

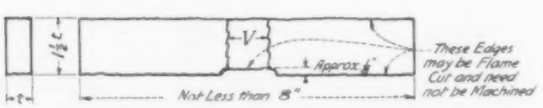
Initial bends shall be made as shown by the broken lines in Fig. 15 and in all cases the initial bends shall be in the same relation to the scribed lines as shown in Fig. 15.

The specimen with the initial bend at each end shall be placed as a strut in a vise or compression machine and pressure applied gradually (that is, without shock) at the ends until failure occurs in the outside fibers of the bend specimen. When a crack is observed in the convex surface of the specimen between the edges, the specimen shall be considered to have failed and the test shall be stopped. Cracks at the corners of the specimens shall not be considered as a failure. The appearance of small defects in the convex surface shall not be considered as a failure if the greatest dimension does not exceed $^1/_{16}$ inch. The specimen shall then be removed from the vise or machine and the maximum distance between the scribed lines measured on the curved surface in $^1/_{100}$ part of an inch this measurement being recorded as the final gage length. This measurement may be made by means of a flexible scale. The difference between the final and initial gage lengths divided by the initial gage length shall be recorded as the precentage of "free bend ductility." The specimen shall then be replaced in the vise or compression machine and pressure again applied until the specimen is broken in two or until it is bent flat upon itself. If the specimen breaks in the welded joint the surface of the fracture shall be examined for lack of soundness.


1½t
V
t
L
These Edges may be Flame Cut and need not be Machined
L (Approximate Minimum) = 3in + 3V
V = Width of the Surface of the Weld.
Weld Reinforcement to be removed flush with Surface of Specimen or slightly below. Any method of Removal is acceptable as a smooth surface is not required.

The Length of The Bend Specimen is immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandatory

Fig. 5—Root Break Test Specimen



Note: If the weld reinforcement exceeds $\frac{1}{4}t$, it shall be removed flush with the surface of the base material. Any method of removal may be used provided the resulting surface on the specimen is reasonably smooth

Fig. 6—Side Break Test Specimen

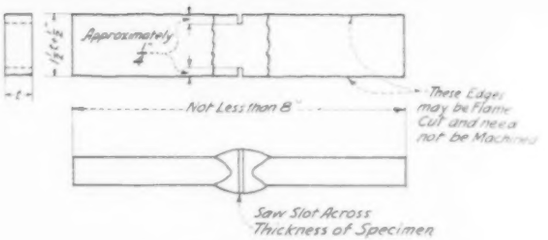


Fig. 7—Nick Break Test Specimen

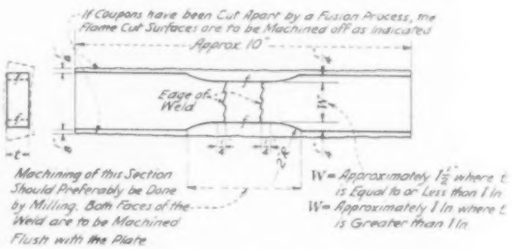

If Coupons have been Cut Apart by a Fusion Process, the Flame Cut Surfaces are to be Machined off as Indicated
Approx. 10"
Edge of Weld
t
t
Machining of this Section Should Preferably be Done by Milling. Both Faces of the Weld are to be Machined Flush with the Plate
W = Approximately 1½" where t is Equal to or Less than 1 In.
W = Approximately 1 In where t is Greater than 1 In

Fig. 8—Reduced Section Tensile Test Specimen for Pipe

(*c*) Root Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 16. The root of the weld shall be opposite the side upon which pressure is applied. If fracture of the specimen does not occur using the method shown in Fig. 16, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surface of the fracture shall be examined for lack of soundness.

(*d*) Side Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 17. If fracture of the specimen does not occur using the method shown in Fig. 17, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of fusion.

(*e*) Nick Break Specimens. The specimen shall be supported as shown in Fig. 18 and broken by a sudden blow or blows applied at the center of the weld. The blow should be applied preferably by a power hammer or falling weight, and be of sufficient intensity to cause a sharp sudden fracture of the specimen through the nicked portion. The surfaces of the fracture shall be examined for lack of soundness.

(*f*) Longitudinal and Transverse Shear Test Specimens. Before testing the length of the individual welds shall be measured and if any weld varies by more than $^1/_{16}$ inch from the length specified in Figs. 14*a* and 14*b*, then the length of each weld and its location shall be recorded. The average size of the fillet welds shall also be recorded.

Each specimen shall be loaded in tension at a uniform rate until fracture occurs, and the

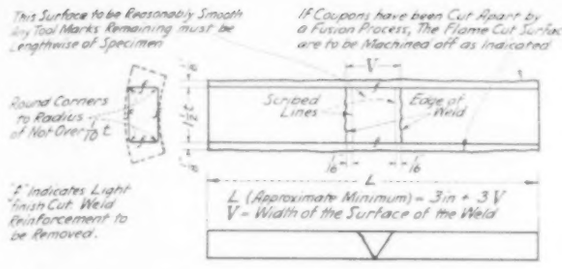

This Surface to be Reasonably Smooth Any Tool Marks Remaining must be Lengthwise of Specimen
If Coupons have been Cut Apart by a Fusion Process, The Flame Cut Surfaces are to be Machined off as Indicated
Round Corners to Radius of Not Over 1/10 t
Scribed Lines
Edge of Weld
"F" Indicates Light Finish Cut. Weld Reinforcement to be Removed.
L (Approximate Minimum) = 3in + 3V
V = Width of the Surface of the Weld
The Length of The Bend Specimen is Immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandatory.

Fig. 9—Free Bend Test Specimen for Pipe

maximum load in pounds shall be recorded. The load in pounds per lineal inch shall be calculated as follows:

$$\frac{\text{Load at Failure in Lb}}{\text{Total Length of Welds through Which Failure Occurs}} = \text{Lb. per Lineal Inch}$$

(*g*) Fillet Weld Break Specimen. The specimen shall be set up for testing as shown in Fig. 19, and broken through the welded joint by blows or pressure applied at *A* as shown in the figure. The surfaces of the fracture shall be examined for lack of soundness.

(*h*) Etch Specimens. The etch specimens shall be prepared for testing as follows: The two cross-sectional surfaces of the welded joint specimen shall be polished to bright smooth surfaces which may be accomplished by filing and polishing with emery cloth and should be completed with the use of emery cloth of 00 grade. If the specimens have been removed by flame cutting they shall be machined, ground or filed to a smooth surface by the removal of not less than $^1/_8$ inch of material below the flame cut surface and they shall then be polished as above. The specimens shall then be etched in a boiling solution of equal parts of hydrochloric acid and water for a sufficient period of time to reveal all lack of soundness that might exist at the cross-sectional surfaces of the specimen.

9. Test Results Required

For each actual process specification to be established there shall be specified definite minimum test values or criteria for each of the tests enumerated in Par. 2.

10. Records

Records shall be kept of the test results.

Part II—Qualification Tests of Welding Operators

1. For the qualification of an operator under any welding process that has been qualified as outlined in Part I, the following procedure shall be used.

2. Types of Test Required

The tests required for the qualification of an operator are limited to those intended for determination of lack of soundness. For each process an operator need be qualified only for the types of joints and positions that he will encounter in construction. The types of tests required are as follows:

A. Single Welded Butt Joints.
  (*a*) Face Break Test.
  (*b*) Root Break Test.
  (*c*) Side Break Test.

B. Double Welded Butt Joints.
  (*a*) Face Break Test.
  (*b*) Side Break Test.

C. For all types of Fillet Welded Joints.
  (*a*) Fillet Weld Break Test.

D. For special types of Welded Joints.
  (*a*) Etch Test.

3. Base Material and Its Preparation

The base material and its preparation for welding shall comply with the Process Specification. For all types of welded joints the length of the weld and the dimensions of the base material shall be such as to provide sufficient material for the test specimens called for hereinafter.

4. Position of Test Welds

A. Classification of Position.

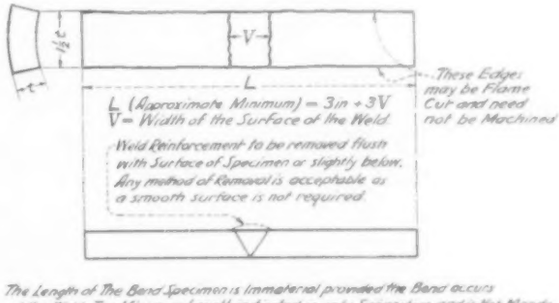
The classification of position shall be the same as specified in Par. 4A of Part I, namely, (*a*) flat; (*b*) horizontal; (*c*) vertical; (*d*) overhead.

B. Butt Joints in Plate.

In making the test welds for butt joints in plate, the test plates shall be placed in an approximately horizontal plane for the (1) Flat and (4) Overhead Positions, and in an approximately vertical plane for the (2) Horizontal and (3) Vertical Positions. The weld metal shall be deposited from the upper side of the test plates for the (1) Flat Position, and from the under side thereof for the (4) Overhead Position. The test welds shall be run horizontally for the (2) Horizontal Position and vertically for the (3) Vertical Position.

C. Butt Joints in Pipe.

Butt joints in pipe shall be classified as (1) horizontal rolled; (2) horizontal fixed; (3) vertical fixed. If a welding operator has been qualified for the horizontal fixed position he may be considered qualified for the horizontal rolled position, provided the procedure for the welding is the same. If a welding operator has been qualified for butt joints in plate for all positions as


1/2 t
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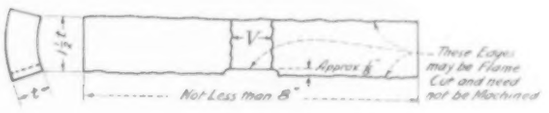
L
These Edges may be Flame Cut and need not be Machined
L (Approximate Minimum) = 3in + 3V
V = Width of the Surface of the Weld
Weld Reinforcement to be removed flush with Surface of Specimen or slightly below. Any method of Removal is acceptable as a smooth surface is not required.
The Length of The Bend Specimen is Immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandato

Fig. 10—Root Break Test Specimen for Pipe



Note: If the weld reinforcement exceeds $\frac{1}{8}t$, it shall be removed flush with the surface of the base material. Any method of removal may be used provided the resulting surface on the specimen is reasonably smooth.

Fig. 11—Side Break Test Specimen for Pipe

specified in Par. 4B above, he may be considered as qualified for all positions in pipe.

The axis of the pipe shall be approximately horizontal for test welds to be made in positions (1) horizontal rolled, and (2) horizontal fixed, and the pipe shall be rolled for (1) and shall not be rolled for (2).

The axis of the pipe shall be approximately vertical for test welds to be made in position (3) vertical fixed, and the pipe shall not be turned while welding.

D. Fillet Welded Joints.

(*a*) A fillet weld made in such a position that the throat is in an approximately vertical plane, and the axis of the weld is approximately horizontal, shall be classified as position (1) flat, and the test plates shall be so placed as to simulate this condition.

(*b*) A fillet weld, one leg of which is on the upper side of an approximately horizontal surface and the other leg is in an approximately vertical plane, with the axis of the weld approximately horizontal, shall be classified as being in position (2) horizontal. The test plates for this position shall be placed one horizontally and the other vertically and the test welds deposited on the upper side of the horizontal surface and against the vertical surface.

(*c*) A fillet weld, one leg of which is on the under side of an approximately horizontal surface and the other leg is in an approximately vertical plane, with the axis of the weld approximately horizontal, shall be classified as being in position (4) overhead. The test plates for this position shall be placed one horizontally and the other vertically, and the test welds deposited on the underside of the horizontal surface and against the vertical surface.

(*d*) Any fillet weld whose axis is at an angle of more than 45 degrees with a horizontal plane shall be classified as being in position (3) vertical. The test plates for this position shall be placed in a vertical plane and the test welds run vertically.

E. Special Types of Welded Joints.

In addition to the above tests, for either or both butt or fillet welded joints, and wherever the conditions for welding in actual construction are such that it may be difficult, because of inaccessibility, to make a sound welded joint, the operator shall make one sample joint simulating the actual construction. The welding of such joint shall be done in the same position and within the same restricted space for the welding operator as will apply in actual construction. The thickness of the base material and the throat of the weld shall be the maximum that will be used in construction except that neither need exceed $1^1/_2$ inches.

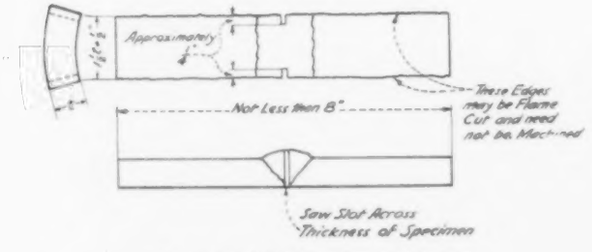

Approximately
Not Less than 8"
These Edges may be Flame Cut and need not be Machined
Saw Slot Across Thickness of Specimen

Fig. 12—Nick Break Test Specimen for Pipe

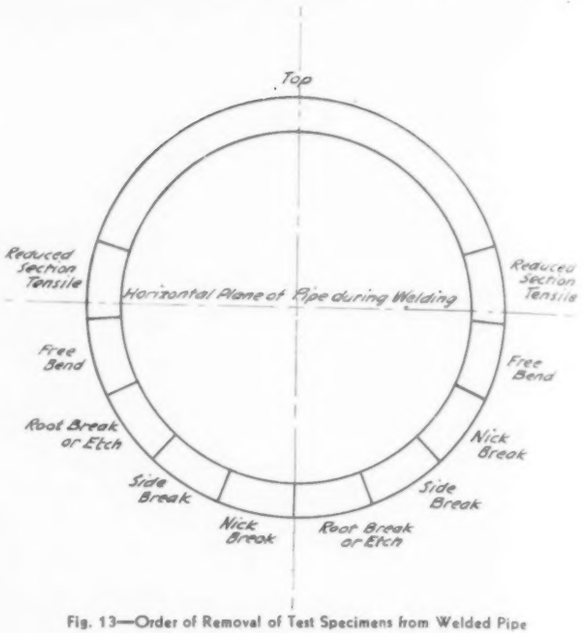


Fig. 13—Order of Removal of Test Specimens from Welded Pipe

5. Number, Type and Size of Test Welds

A. Butt Joints in Plate.

(*a*) For butt joints in plate the operator shall make for each process and position one test weld in the maximum thickness of material for which he is to be qualified, except that the thickness need not exceed $1^1/_2$ inches.

B. Butt Joints in Pipe.

(*a*) For butt joints in pipe the operator shall make one test weld for each process and position to be used in construction. The diameter and thickness of pipe for the test weld shall be the maximum to be used in construction except that the pipe used in the test shall not be less than 4 inch standard weight and need not be more than 8 inch double extra heavy.

C. Fillet Welded Joints.

(*a*) For fillet welded joints the operator shall make, for each process and position to be used in construction, one break test weld with the maximum size single pass fillet weld and one break test weld with the minimum size multiple pass fillet weld that will be used in construction.

(*b*) The fillet weld break test weld shall be made as shown in Fig. 2 and the thickness of the base material shall be at least $^1/_8$ inch greater than the size of the fillet.

D. Special Types of Welded Joints.

In addition to the above tests, for either or both butt or fillet welded joints, and wherever the conditions for welding in actual construction are such that it may be difficult, because of inaccessibility, to make a sound welded joint, the operator shall make one sample joint simulating the actual construction. The welding of such joint shall be done in the same position and within the same restricted space for the welding operator as will apply in actual construction. The thickness of the base material and the throat of the weld shall be the maximum that will be used in construction except that neither need exceed $1^1/_2$ inches.

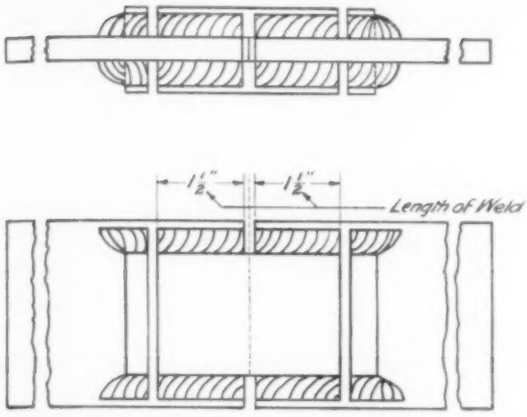


Fig. 14a—Preparation of Longitudinal Shear Test Specimen

6. Welding Procedure

The welding procedure shall comply in all respects with the Process Specification.

7. Test Specimens—Number, Type and Preparation

(*a*) Butt Welded Joints. From each test weld there shall be taken the following test specimens which shall be prepared for testing as shown in the figures referred to:

For Single Welded Butt Joints in Plate:

One Face Break Specimen	Fig. 5
One Root Break Specimen	Fig. 5
One Side Break Specimen	Fig. 6

For Double Welded Butt Joints in Plate:

Two Face Break Specimens	Fig. 20
One Side Break Specimen	Fig. 6

For Butt Welded Joints in Pipe:

Two Face Break Specimens	Fig. 10
Two Root Break Specimens (not required where backing up strip is used)	Fig. 10
Two Side Break Specimens	Fig. 11

The test specimens (except for horizontal fixed position welds in pipe) shall be removed in the order given above except that no two specimens of the same type shall be removed adjacent to each other. For horizontal fixed position welds the test specimens shall be removed as shown in Fig. 21.

(*b*) Fillet Welded Joints. The fillet break test welds need no preparation for testing.

(*c*) Special Types of Welded Joints. From each test weld there shall be removed, at such locations as will best reveal lack of soundness of the welded joint, not less than three etch test specimens. These specimens shall be a cross section of the welded joint including at least 1/2 inch of base material on each side of the weld. The width of such specimens in the direction of the weld need not exceed 1/4 inch.

8. Method of Testing Specimens

(*a*) Face Break Test Specimens. The specimen shall be supported and pressure applied as shown in Fig. 16, except that the face of the weld shall be opposite the side upon which pressure is applied. For double welded butt joints one specimen shall be tested with one face down and the other specimen with the opposite face down.

If fracture of the specimen does not occur using the method shown in Fig. 16, the specimen shall be removed from the fixture and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of soundness.

(*b*) Root Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 16. The root of the weld shall be opposite the side upon which pressure is applied. If fracture of the specimen does not occur using the method shown in Fig. 16, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of soundness.

(*c*) Side Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 17. If fracture of the specimen does not occur using the method shown in Fig. 17, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of fusion.

(*d*) Fillet Weld Break Specimens. The specimen shall be set up for testing as shown in Fig. 19, and broken through the welded joint by blows or pressure applied at *A* as shown in the figure. The surfaces of the fracture shall be examined for lack of soundness.

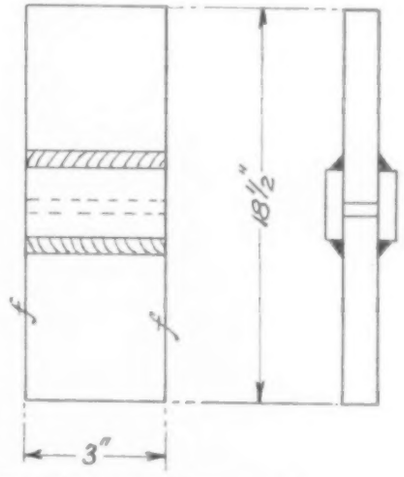
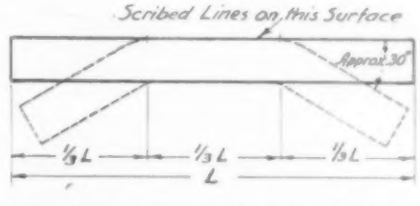


Fig. 14b—Preparation of Transverse Shear Test Specimen



Dotted Lines show preliminary bends which may be made in any manner provided no concentrated bending stress is placed on the weld.

Fig. 15—Position of Initial Bends in Free Bend Test Specimen

(e) Etch Specimens. The etch specimens shall be prepared for testing as follows: The two cross-sectional surfaces of the welded joint specimen shall be polished to bright smooth surfaces which may be accomplished by filing, and polishing with emery cloth and should be completed with the use of emery cloth of 00 grade. If the specimens have been removed by flame cutting they shall be machined, ground or filed to a smooth surface by the removal of not less than $^1/_8$ inch of material below the flame cut surface and they shall then be polished as above. The specimens shall then be etched in a boiling solution of equal parts of hydrochloric acid and water for a sufficient period of time to reveal all lack of soundness that might exist at the cross-sectional surfaces of the specimen.

9. Test Results Required

There shall be specified definite minimum test values or criteria for each of the tests enumerated in Par. 2.

10. Retests

In case an operator fails to meet the requirements on one or more test welds a retest may be allowed under the following conditions:

1. An immediate retest may be made which shall consist of two test welds of each type on which he failed, all of which shall meet all the requirements specified for such welds.
2. A retest may be made after the lapse of one week provided there is evidence that the operator has had further training or practice. In this case only one set of test welds of each type on which he failed need be made.

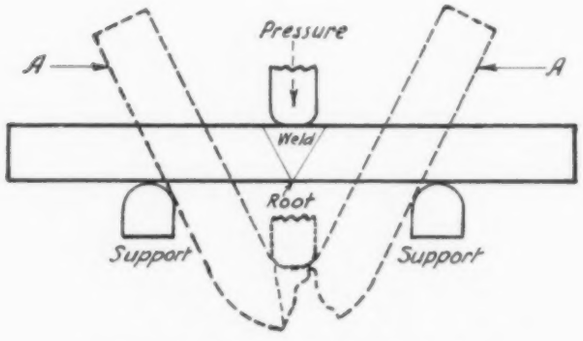


Fig. 16—Method of Testing Root Break Test Specimen

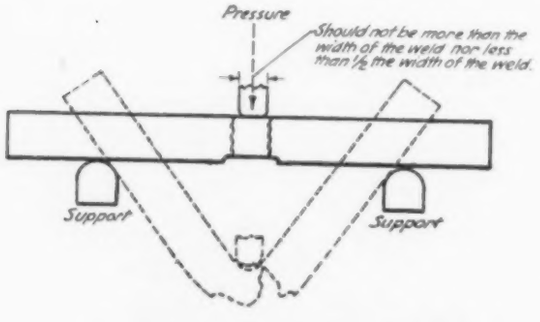


Fig. 17—Method of Testing Side Break Test Specimen

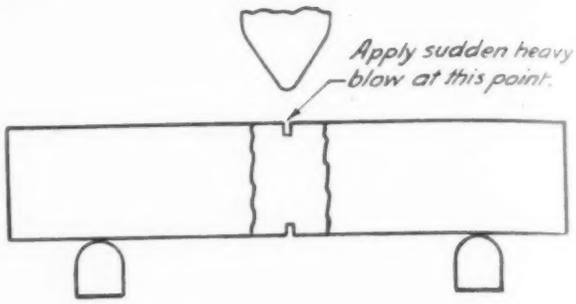


Fig. 18—Method of Testing Nick Break Test Specimen

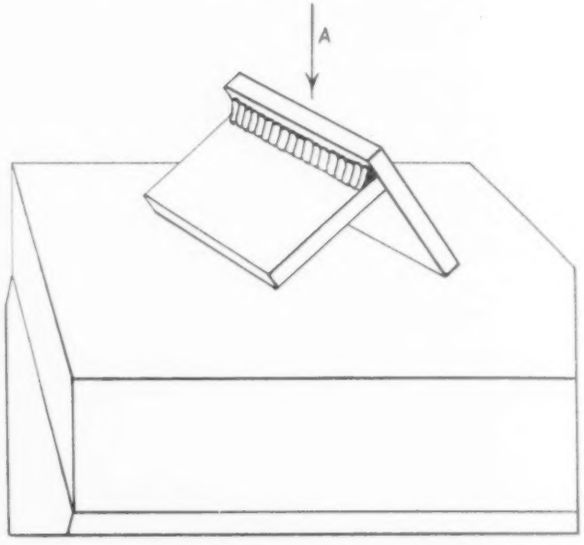


Fig. 19—Method of Testing Fillet Weld Break Specimen

11. Period of Effectiveness

The qualification tests herein specified shall be considered as remaining in effect for a period to be determined by the various code bodies adopting these Rules, unless the welding operator be unemployed for some given period of time, or unless there is some specific reason to question an operator's qualifications, in which case he shall be required to requalify.

12. Records

Copies of the record for each qualified welder shall be kept by the manufacturer.

APPENDIX

Defects and Lack of Soundness

Defects are defined as gas pockets, slag inclusions and lack of fusion exceeding . . . .* inches in greatest dimension.

Lack of soundness shall be evaluated by the total depth of all "zones of defects," measurements being made of such depths on a line or plane parallel to the throat of the weld. A "zone of defect" is defined as the area within two lines perpendicular to the throat of the weld and bounding any one defect, or any group of defects whose depths are overlapping. Illustrations of typical cases of "zones of defects" and the total depth of such zones are given in Fig. 22.

* These values should be given by the code authorities adopting this standard procedure.

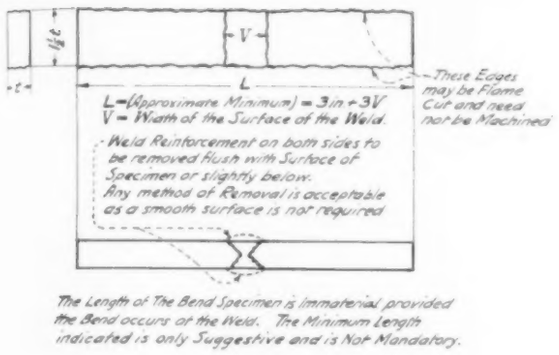

t
V
L
These Edges may be Flame Cut and need not be Machined
L=(Approximate Minimum) = 3in.+3V
V = Width of the Surface of the Weld.
Weld Reinforcement on both sides to be removed Flush with Surface of Specimen or slightly below. Any method of Removal is acceptable as a smooth surface is not required
The Length of The Bend Specimen is immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandatory.

Fig. 20—Face Break Test Specimen

The permissible total depth of all zones of defects on any plane parallel to the throat of the weld shall not exceed . . . .%* of the specified weld throat dimension in the case of fillet welds, or of the thinner of the two parts joined in the case of butt welds.

The length of any permissible defect shall not exceed. . . . .* times the plate thickness, nor shall any two defects be closer together than . . . . .* times the plate thickness.

SPECIFICATIONS FOR OXYACETYLENE WELDING OF

(State Class of Objects to Be Welded)

Date.....

Process: The welding shall be done by the Oxyacetylene Process.

Base Metal: The base material shall conform to the Specifications for (Insert here reference to a standard A. S. T. M. or Code designation or give the chemical analysis and physical properties).

Filler Metal: The filler metal shall be that known as (State the name of manufacturer, the trade name and number or other specific designation of the wire used).

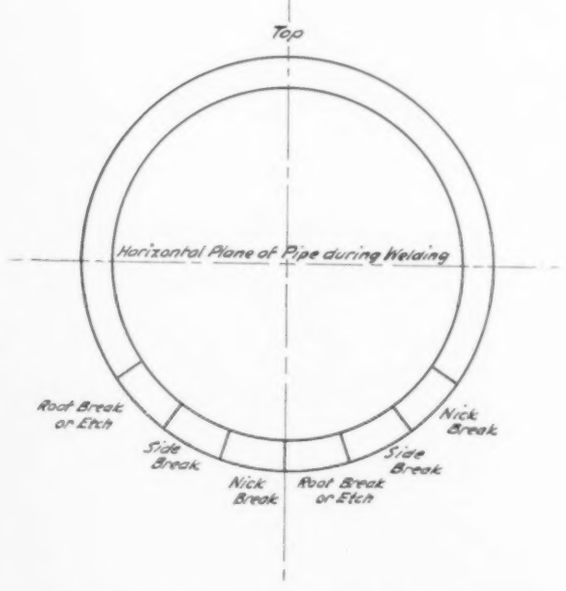


Fig. 21—Order of Removal of Test Specimens from Pipe

Preparation of Base Material: The edges or surfaces of the parts to be joined by welding shall be prepared by (State whether sheared, machined, ground, flame cut, etc.), as shown on the attached sketches and shall be cleaned of all oil or grease and excessive amounts of scale or rust, except that a thin coat of linseed oil, if present, need not be removed. (The sketches referred to should show the arrangement of parts to be welded with the spacing and details of the welding groove, if used. Such sketches should be comprehensive and cover the full range of material or base metal thicknesses to be welded.)

Size of Welding Tip: The size of welding tip used shall be as shown on the attached sketches. (The sketches referred to may be the same as mentioned under "Preparation of Base Material" or may be a separate set. They should show the range of thicknesses for which any one size of tip is to be used.)

Nature of Flame: The flame used for welding shall (State whether a neutral flame or one with slight excess of acetylene is to be used).

Method of Welding: The method of welding used shall be that known as (describe whether "backhand" or "forehand").

Number of Layers of Welding: The number of layers of welding used shall be as shown on the attached sketches. (The sketches referred to may be the same as mentioned under "Preparation of Base Material" or may be a separate set. They should show the range of thicknesses for which one, two or more layers are used.)

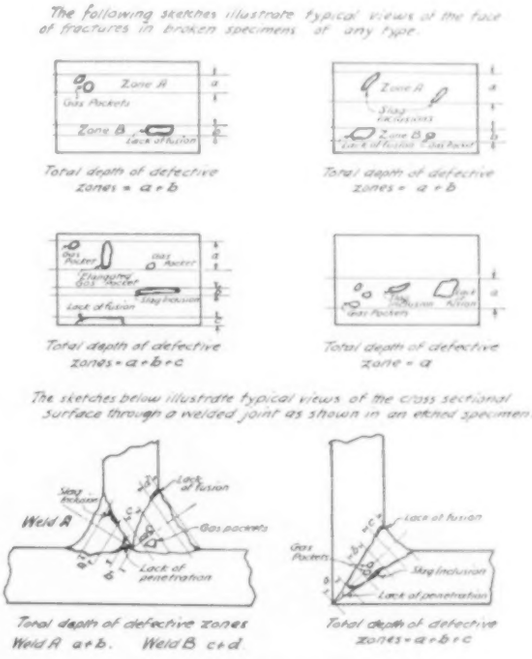

The following sketches illustrate typical views of the face of fractures in broken specimens of any type.
Zone A
Gas Pockets
Zone B
Lack of fusion
Total depth of defective zones = a+b
Slag Inclusions
Total depth of defective zones = a+b
Total depth of defective zones = a+b+c
Total depth of defective zone = a
The sketches below illustrate typical views of the cross sectional surface through a welded joint as shown in an etched specimen.
Weld A
Slag Inclusion
Lack of fusion
Gas pockets
Lack of penetration
Total depth of defective zones Weld A a+b. Weld B c+d.
Gas Pockets
Lack of fusion
Slag Inclusion
Lack of penetration
Total depth of defective zones = a+b+c

Fig. 22—Typical Cases of Zones of Defects

Cleaning: All slag or flux remaining on any layer of welding shall be removed before laying down the next successive layer.

Defects: Any cracks or blow-holes that appear on the surface of any layer of welding shall be removed by chipping or grinding before depositing the next successive bead of welding.

Peening: Each layer of welding shall be (lightly, moderately or heavily) peened with a blunt tool. (This paragraph is to be inserted if peening is made a part of the procedure.)

Treatment of Under Side of Welding Groove: Prior to welding the under or second side of the groove, all metal that has dripped through shall be removed and the groove shall be chipped or machined to permit complete penetration of the welding applied on the under side. (This paragraph is to be inserted where the practice described is followed.)

Heat Treatment: The heat treatment shall consist of heating the (completed object or the welded joint and adjacent material as the case may be) to a uniform temperature of not less than ..... deg F. nor more than ..... deg F. and shall be held at that temperature for a period of time corresponding to ..... hour per inch of base material thickness. (This paragraph is to be inserted where the practice described is followed.) The object (or the welded joint and adjacent material) shall then be (allowed to cool slowly in the furnace or in still air at atmospheric temperature as the case may be).

Name of Manufacturer

SPECIFICATIONS FOR METALLIC ARC WELDING OF

(State Class of Objects to Be Welded)

Date.....

Process: The welding shall be done by the Metallic Arc Process.

Base Metal: The base material shall conform to the Specifications for (Insert here reference to a standard A. S. T. M. or Code designation or give the chemical analysis and physical properties).

Filler Metal: The filler metal shall be that known as (State the name of manufacturer, the trade name and number or other specific designation of the wire used).

Preparation of Base Material: The edges or surfaces of the parts to be joined by welding shall be prepared by (State whether sheared, machined, ground, flame cut, etc.) as shown on the attached sketches and shall be cleaned of all oil or grease and excessive amounts of scale or rust. (The sketches referred to should show the arrangement of parts to be welded with the spacing and details of the welding groove, if used. Such sketches should be comprehensive and cover the full range of material or base metal thicknesses to be welded.)

Nature of Electric Current: The current used shall be (State here whether direct or alternating and if alternating give the frequency). The base material shall be on the (State whether negative or positive) side of the line.

Number of Beads of Welding and Current Characteristics: The number of beads of welding, the diameter of electrode for each bead, and the amperage and voltage values during welding for each bead shall be substantially as shown on the attached sketches. (The sketches referred to may be the same as mentioned under "Preparation of Base Material" or may be a separate set. They should show for the minimum and maximum thicknesses and for several intermediate thicknesses of base material the manner in which the beads of welding are deposited, whether string beads or woven, and for each head the diameter of electrode used and the amperage and voltage values used *while welding* should be given.)

Cleaning: All slag or flux remaining on any bead of welding shall be removed before laying down the next successive bead.

Defect: Any cracks or blow-holes that appear on the surface of any bead of welding shall be removed by chipping or grinding before depositing the next successive bead of welding.

Peening: Each bead of welding shall be (lightly, moderately or heavily) peened with a blunt tool. (This paragraph is to be inserted if peening is made a part of the procedure.)

Treatment of Under Side of Welding Groove: Prior to welding the under or second side of the groove, all oxidized metal that has dripped through shall be removed and the groove shall be chipped or machined to permit complete penetration of the welding applied on the under side. (This paragraph is to be inserted where the practice described is followed.)

Heat Treatment: The heat treatment shall consist of heating the (completed object or the welded joint and adjacent material as the case may be) to a uniform temperature of not less than ... deg. F. nor more than ... deg. F. and shall be held at that temperature for a period of time corresponding to ..... hour per inch of base material thickness. (This paragraph is to be inserted where the practice described is followed.) The object (or the welded joint and adjacent material) shall then be (allowed to cool slowly in the furnace or in still air at atmospheric temperature as the case may be).

Name of Manufacturer

SPECIFICATIONS FOR CARBON ARC WELDING OF

(State Class of Objects to Be Welded)

Date.....

Process: The welding shall be done by the Carbon Arc Process.

Base Metal: The base material shall conform to the Specifications for (Insert here reference to a standard A. S. T. M. or Code designation or give the chemical analysis and physical properties).

Filler Metal: The filler metal shall be that known as (State the name of manufacturer, the trade name and number or other specific designation of the wire used).

Preparation of Base Material: The edges or surfaces of the parts to be joined by welding shall be prepared by (State whether sheared, machined, ground, flame cut, etc.), as shown on the attached sketches and shall be cleaned of all oil or grease and excessive amounts of scale or rust. (The sketches referred to should show the arrangement of parts to be welded with the spacing and details of the welding groove, if used. Such sketches should be comprehensive and cover the full range of material or base metal thicknesses to be welded.)

Nature of Electric Current: The current used shall be (State here whether direct or alternating and if alternating give the frequency). The base material shall be on the (State whether negative or positive) side of the line.

Details of Welding: The number of beads of welding, carbon diameter, speed of welding head, amperes and volts for each bead or layer of welding shall be substantially as shown on the attached sketches. (The sketches referred to may be the same as mentioned under "Preparation of Base Metal" or may be a separate set. They should show for the minimum and maximum thicknesses and for several intermediate thicknesses of base material the manner in which the beads of welding are deposited giving the maximum or minimum permissible values for the variables referred to above.)

Shielding of Arc: The arc shall be shielded by the use of (State the nature of the material used, the name of the manufacturer, the trade name and manufacturer's number or other designation of the material).

Cleaning: All slag or flux remaining on any bead of welding shall be removed before laying down the next successive bead.

Defects: Any cracks or blow-holes that appear on the surface of any bead of welding shall be removed by chipping or grinding before depositing the next successive bead of welding.

Peening: Each bead of welding shall be (lightly, moderately or heavily) peened with a blunt tool. (This paragraph is to be inserted if peening is made a part of the procedure.)

Heat Treatment: The heat treatment shall consist of heating the (completed object or the welded joint and adjacent material as the case may be) to a uniform temperature of not less than ..... deg. F. nor more than ..... deg. F, and shall be held at that temperature for a period of time corresponding to ..... hour per inch of base material thickness. (This paragraph is to be inserted where the practice described is followed.) The object (or the welded joint and adjacent material) shall then be (allowed to cool slowly in the furnace or in still air at atmospheric temperature as the case may be).

Name of Manufacturer

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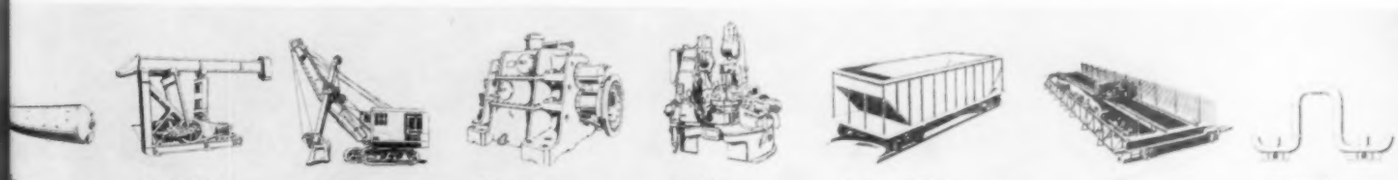

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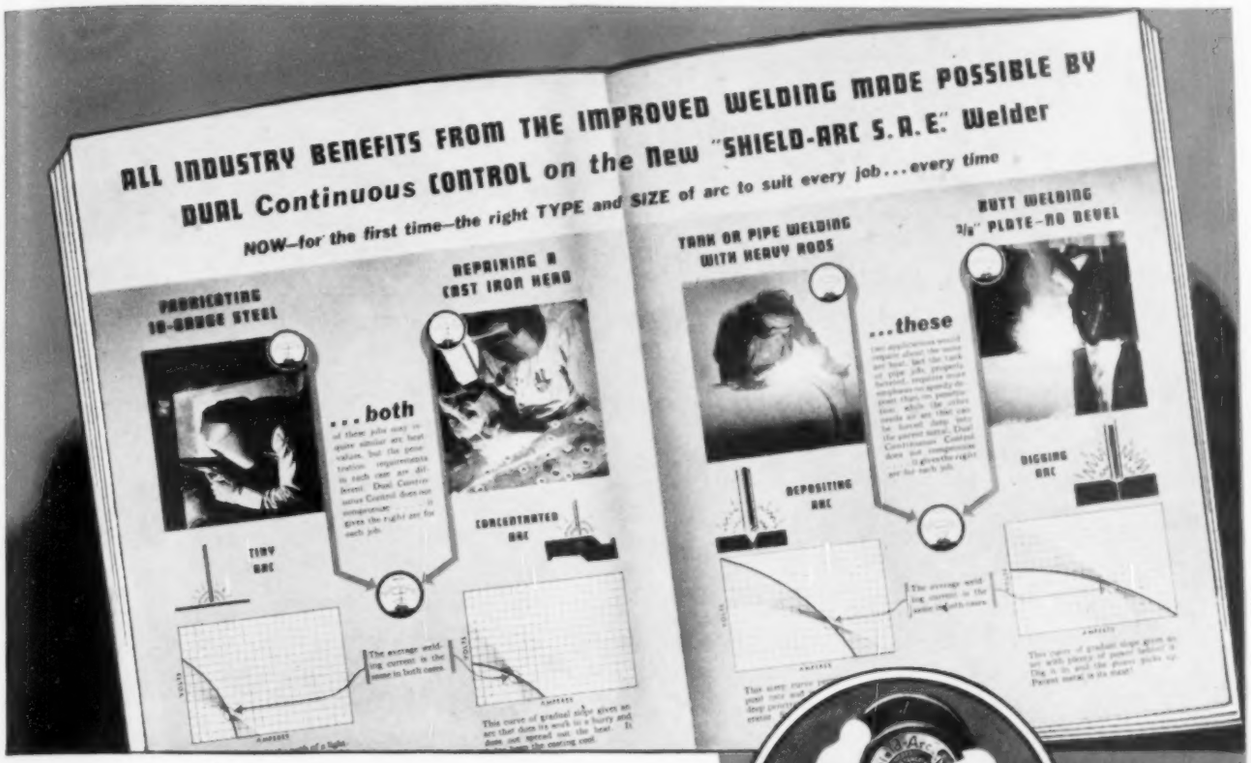
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An AIRCO Cutting Torch *helps to make history!*

Airplane view of the bridge from the San Francisco end. Above: Cutting the chain: Left to right, Earl Lee Kelly, State director of Public Works; Governor Merriam; Charles H. Purcell, who engineered the bridge; H. W. Saunders, Air Reduction San Francisco District Manager. Acme photos.

• **ONE OF THE GREAT ENGINEERING FEATS OF MODERN TIMES was brought to a spectacular climax at the ceremonies on November 12th which marked the opening of the world's largest bridge, linking San Francisco to Oakland across San Francisco Bay.**

On that history-making occasion the customary cutting of a silk ribbon gave way to a far more stirring and symbolic innovation. Using the torch of an AIRCO-DB emergency cutting outfit, Governor Frank Merriam of California neatly severed a chain stretched across the San Francisco end of the bridge. The ceremony was repeated in the center of the span and at the Oakland end.

And it was fitting that an AIRCO torch should be accorded this signal honor, for AIRCO cutting and welding equipment was used by many of the contractors who shared the work of construction.

AIRCO salutes these contractors and is proud that AIRCO equipment had a part in helping them to bring to successful completion this monumental bridge building achievement.

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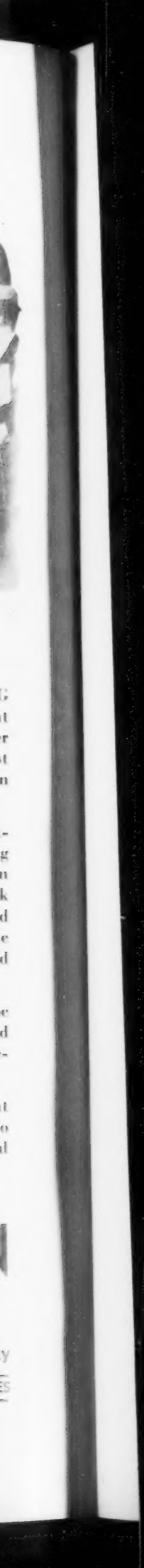
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